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MARS: A Strategy for Exploration

Report of a Study by the

Mars Science Advisory Committee

to the

Planetary Programs Office

National Aeronautics and Space Administration

Washington, D.C.

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FOREWORD

The Mars Science Advisory Committee was established in September 1972 by the Planetary Programs Office, NASA Headquarters, Washington, D. C. The Committee served to advise NASA on the continued exploration of the atmosphere, surface, and interior of Mars, and the search for evidence of life, following the Viking 1975 mission. During the course of several meetings held between September 1972 and June 1973, the Committee developed scientific objectives for the continued exploration of Mars and reviewed current and expected knowledge about the planet. Following examination of engineering aspects of various mission options and review of on-going advanced instrumentation development programs, the Committee defined a strategy for exploration of Mars from 1977 and beyond. Although specific instruments and experiments for future missions were discussed, it was not the purpose of this Committee to propose specific payloads. Instead, emphasis was placed on mission type. This final report summarizes the Committee's deliberations and sets forth a set of recommendations for use by NASA in planning future planetary missions to Mars.

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RECOMMENDATIONS AND CONCLUSIONS

1. Scientific exploration of Mars after Viking '75 should continue to have high priority in the NASA planetary program.
2. The next mission following Viking '75 should be planned so as to be responsive to the data returned from Viking '75.
3. The missions of greatest scientific value are:
   a. Viking lander and orbiter in 1979, necessarily with improved geoscience, biological science, and orbiter science. Some rover capability would be desirable. This is consistent with the 75 kg extra launch weight available in the 1979 opportunity.
   b. Return to earth of a surface sample of Mars (1981 launch, 1984 return).
4. Only one of these missions can be flown in 1979-81, so as not to unbalance the planetary program.
5. We recognize a number of problems associated with the sample return mission:
   a. High and uncertain cost ($600 M?).
   b. Need for development of new technology.
   c. Possible hazards of back contamination.
6. During FY 74, intensive efforts should be carried out in order to:
   a. decide whether a 1981 sample return mission should be requested.
   b. identify those instruments which require development in order

to maximize the scientific value of Viking '79.

c. obtain agreement for European development of a rover for Viking '79.

7. If the decision on MSSR '81 is negative, provide adequate funding ($5 M in FY 75, $15 M in FY 76) to develop new scientific instruments for Viking '79.

8. Select the Viking '79 payload in 1976 following the return of data from Viking '75.

9. A long-lived 1979 orbiter has great scientific potential and is recommended if neither of the highest priority missions (Viking '79 or Mars sample return) should be selected.

10. The potential for Mars studies by Pioneer-class landers and entry probes, based on experience derived from the Pioneer Venus program, should be thoroughly explored. These could be strong candidates for lower cost, more specialized missions in the 1980's.

CHAPTER I

SCIENTIFIC OBJECTIVES OF THE EXPLORATION OF MARS

To the planetary astronomer a decade ago the planet Mars was a ruddy shimmering disc, a white polar cap and vague dark markings. With much patience, the boundaries of these dark areas could be reproducibly mapped. For fleeting moments more fine detail could be seen, but could not be reliably recorded.

Now, as a result of four Mariner missions, Mars is a new world with great volcanoes and lava fields, canyonlands of continental dimensions, heavily cratered terrains at first glance reminiscent of the moon, and channels resembling terrestrial meandering and braided rivers. In 1976 Viking will provide an even closer view of the planet. The local features of its surface will be photographed, its rocks and soil will be analyzed, and evidence for Martian life will be sought.

Building upon these exploratory investigations, the study of Mars will take its place in the continuing investigation of the fundamental nature of planetary bodies, in their similarities and differences, and ultimately help lead to a more general theory of planets (comparative planetology). So far this type of investigation has been limited to two planetary bodies - Earth and Moon. Terrestrial geology and the lunar program continue to make remarkable progress in unraveling the early history of these bodies and their subsequent evolution. Valuable as the understanding of these objects is there is an added complication arising from their being at the same position in the solar system and gravitationally coupled to one another. It is thus difficult to decide whether certain processes, such as the early heating and chemical differentiation of Earth and Moon, were a peculiar property of the Earth-Moon system or a more general property of planets of the solar system. Mars currently offers the best opportunity to decide this question.

Mars is in several ways a good choice of the next planet to study in detail. In terms of size, density and possibly in volatile element content, it sits between Earth and Moon. Its surface is uniquely accessible. Its atmosphere is sufficiently dense to be of meteorological interest and to be an agent in modifying the surface of the planet, yet is sufficiently thin that modification of the surface has been far less extensive and probably less complex than that on Earth. Both internal and surficial geological processes have manifestly occurred, but do not appear to have been so widespread as to erase the early history of the planet. Because of the relatively moderate temperatures, the presence of an atmosphere and of water in the forms of vapor and ice, Mars is the prime target for biological exploration of the solar system beyond Earth. Many biologists would argue that it is the only other place in the solar system where there is any reasonable chance of finding life. It is the prime target in the search for extraterrestrial living organisms or their abiological precursors.

The scientific objectives of the exploration of Mars are determined by their relevance to "comparative planetology" as described above. Only in the context of such planetological objectives are measurements and the flight instruments which perform the measurements relevant. By proper formulation of these questions, a valid exploration strategy and instrument payload can be developed. Most of the scientific questions are those which would be asked of any planet. However, the approaches taken in answering them will be dictated by the special opportunities and limitations peculiar to Mars. Some of the major questions are discussed in more detail in the remaining sections of this chapter. The two following chapters discuss the contributions that Mariner 9 has made and that Viking is expected to make toward answering these questions. Building on the knowledge already gained and expected from these missions, we then proceed to develop the strategy for the next steps in Martian exploration.

I.1. What is the Basic Physical and Compositional Structure of Mars?

The Earth's layered structure of crust-mantle-core may be the result of an internal wholly post-formational process or may be partly a characteristic of inhomogeneous planetary accretion. The smaller and compositionally different Moon also has a crust and mantle but may or may not have a core. Geophysical data on the gross structure of Mars will provide an additional basis for separating the effect of size from that of composition, both of which influence internal structure and thermal activity.

Directly related to the internal structure and composition is the origin of planetary magnetic fields. The Earth has a large magnetic field, thought to be generated by convection of conducting fluids in an iron core. The Moon has no field now being generated but shows evidence that a weak field did exist over 4 billion years ago. The origin of this weak field may have been external, possibly related to large magnetic fields in interplanetary space as the solar system formed. Measurements on the strength and structure of the Martian magnetic field, along with data on presence or absence of a fluid core, will bear directly on how planetary magnetic fields arise.

Inevestigation of the elemental and mineralogical composition of Mars bears on two important questions: 1) What were the solar system conditions under which the planet formed? and 2) What processes have altered or modified the early chemical and physical state of Mars? Ideally, in order to answer the first question, one must know the bulk starting composition of the planet, from which estimates can be made of the temperature, pressure and composition of that part of the solar nebula from which Mars material condensed. In practice one cannot determine the bulk starting composition because the initial state has been modified and because we can directly investigate only the geologic unit now exposed on the surface. The problem of modification is addressed by investigating the composition and the formative processes of the various surface units after which inference can be made regarding the primordial material. For example, by such methods lunar material can be shown to be depleted, on a planetary scale, in the low temperature, volatile-rich, components of the solar system starting material. The Moon must have formed, at least in part, from material initially formed in the hotter regions of the nebula than did material making up the more volatile-rich Earth.

The investigation of the surface rock composition and processes relates more directly to the evolution of the planet. First, analysis of the surface units leads to knowledge of the actual formational process. For example, determination of the rock types in the Tharsis region will lead to a comprehension of the formation of the enormous volcanic mountains such as Nix Olympica, ten times larger both vertically and horizontally than most terrestrial volcanic complexes. Assuming that rock to have been a lava, one can, in conjunction with laboratory data, estimate composition of the deep interior rock which was the source region of the lavas. Limits on such interpretations and better delineation of the interior distribution of the parent materials are supplied by seismic means. Analysis of the sediments of the terrain units near the mouth-regions of the large canyons is expected to shed light on the putative erosional process creating the canyons, i.e., the presence of hydrous minerals would support an interpretation of running water as the erosive agent. As a last example, the composition of the heavily-cratered uplands is of special interest. It is apparently the oldest exposed Mars geologic unit and may, by analogy with the

Moon, represent the early-formed crust. As such it is less evolved than, say, the lavas of the volcanic regions, and takes us a step closer to the starting composition.

I.2. What Processes Have Been Modifying the Martian Surface; What Are Their Time Scales?

The question is directly linked to Mariner photography which shows conclusive evidence that the Martian surface has been modified to different degrees in different parts by volcanism, meteoroid cratering, wind and possibly water erosion, and sedimentation. The volcanic regions indicate that Mars melted internally, at least locally, some time after its origin. Such volcanism presumably released gases to form the atmosphere and water possibly to form a transient hydrosphere and to supply the condensable materials now composing the polar caps. Determining the age of volcanic features would lead to models of internal thermal history and bears on past climatological history. Determing the ages of highly cratered and less cratered terrain will, together with lunar data, allow attribution of the high rate of early lunar cratering to debris either in the Earth-Moon system or in the entire solar system.

Part of the problem in deciphering past Martian history is the determination of the roles of, and interrelations among, different erosion-sedimentation mechanisms in creating new morphologies and destroying old ones. For example, meteoroid impacts fragment surface material, gases released by volcanic activity form an atmosphere, the atmosphere erodes the meteoroid-generated fragmental debris from some regions and deposits it in others. The aeolian sediments fill in small craters, create dune fields, and become trapped in polar cap condensates. The polar caps have evidently changed in extent and position through time.

I.3. What is the Composition of the Atmosphere?

We are concerned with both the present state and the history of the atmosphere. Knowledge of the present state includes knowledge of the composition as well as an understanding of the chemical and physical processes responsible for maintaining that composition. The absolute abundances of the rare gases and of nitrogen are of great interest, particularly in bounding the history of the planet. The abundance of neon is an important clue to the question of whether or not there is any remnant of a primordial atmosphere. Argon may give an indication of the amount of outgassing which has taken place, and the argon to CO_2 ratio can be interpreted as an indicator of the similarity of outgassing on Mars to outgassing on Earth, or it may be an indicator of whether or not there is a reservoir of frozen or absorbed CO_2. The concentration of nitrogen, an important element in bio-organic molecules, and its isotopic abundances may be controlled by non-thermal escape. Thus, measurements of nitrogen concentrations or a refinement in the upper limit on nitrogen would serve as an indicator of the nature of escape processes, not only those acting now but possibly also those occurring in the past. The concentration of helium, if it can be measured, also gives an indication of the nature of escape processes.

The chemistry of even the major atmospheric constituent, CO_2, is not yet understood. It is dissociated rapidly to CO and O, but since the observed dissociation in both the lower and upper parts of the atmosphere (up to 200 km) is very small, recombination must also be occurring very rapidly. CO_2 recombination is catalyzed by reactions to CO and O with the dissociation products of water vapor. It may also be catalyzed by reactions at the surface. But, these processes only occur in the lower atmosphere, and enormous vertical mixing rates are required if they are to account for the undissociated state of the upper atmosphere.

Ozone may be an important clue in this puzzle since it participates in reactions with the products of H_2O dissociation. A thorough understanding of the behavior of ozone in the Mars atmosphere is of added interest because some of the same reactions may influence the concentration of ozone, an absorber of lethal ultraviolet radiation, in the Earth's atmosphere.

The mechanisms controlling the seasonal and regional variation in water vapor probably involve either transport to polar caps and deposition in, or sublimation from, the caps, or they may involve some sort of equilibrium with adsorbed water in the soil. Since water is a key to the understanding of the surface environment, both geochemically and biologically, the nature and location of water vapor sources and sinks and the amounts of water stored in various types of reservoirs are questions of great interest. Furthermore, the abundance, rate of outgassing, and rate of escape of water are all important points of comparison for the Earth, the Moon, and Mars.

I.4. What is the Circulation and Turbulence in the Atmosphere?

The large-scale circulation is of interest in itself, again as a point of reference with the Earth's atmosphere, and also because it plays a major role in distributing and mixing the components of the atmosphere, as discussed above. For example, water vapor, ozone, and dust are all variable constituents of the atmosphere which are systematically transported from one region to another. The probable important role played by vertical mixing, either as a direct result of the large-scale circulation or as a consequence of turbulence, has already been mentioned. On the Earth, mixing in the stratosphere and mesosphere seems to depend largely on the circulation of the lower atmosphere. The large-scale motion of the upper atmosphere responds to the motion of the lower atmosphere, and when sufficiently large amplitude is achieved, it breaks down into turbulence. If this is also the case on Mars, and there is every reason to believe that it is, then our attention should focus on the lower atmosphere circulation, although observations of the circulation in the 20-100 km region would also be useful. It should be noted that the present upper limit of N_2 abundance is dependent on models for mixing processes; but N_2 measurements near the surface would remove this model dependence.

A useful understanding of the circulation requires not only a description, but also an understanding, of the mechanisms for producing the observed winds. The ways in which the atmosphere responds to the heating imposed on it, to the underlying topography, to rotation, and to the effects of mass condensation are of great importance; their understanding may provide new insights applicable to our own atmosphere. The very large-scale dust storms which occur with great regularity are circulation processes which are not yet understood. Such storms may play a significant role in modifying the surface, and their origin seems to depend critically on the distribution of solar radiation. Monitoring of seasonal variations in the circulation is needed to unravel this problem.

I.5. What is the Origin and Past History of the Atmosphere?

On any planet, we would like to know whether there was a primordial atmosphere, what are rates of outgassing now and in the past, whether the atmosphere ever had a substantially different composition and/or climate, and how and why any major variations in composition or climate took place. These questions are of particular interest in the case of Mars because of its similarity to the Earth. The answers for Mars would provide benchmarks against which to check our notions of the history of the Earth's atmosphere. They are also essential factors in understanding the presence or absence of biological evolution on Mars.

They are also, unfortunately, the most difficult to answer. We do not yet have a satisfactory understanding of the early history of the Earth's atmosphere. The chemistry of the Martian atmosphere appears to be much simpler and the history may be correspondingly easier to unravel, but we can only hope to arrive at answers by thoroughly understanding the factors influencing the present composition and climate. Elements of this understanding will depend on many aspects of Martian investigation, and not just on studies directed specifically toward the atmosphere. The composition of the surface rocks, for example, will give an indication of the volatiles which they once contained. The composition and variations in composition of volcanic rocks are of particular interest in this regard. The surface morphology variations may provide clues to the age of the atmosphere. If an absolute age scale can be determined, as has been done on the moon, then the relative time scale provided by crater distributions may be used to date numerous widespread erosional and depositional events caused by the atmosphere. The situation is unlike that on the Earth where surface modification takes place on a very short time scale. Instead, morphological evidence may allow inferences to be drawn about the very early history of Mars.

A key element in the problem of climate change is the question of whether or not a large CO_2 reservoir exists. If it does not, then it is unlikely that any major variations in climate could have occurred; at least, not unless an earlier dense atmosphere has escaped. Direct exploration of the residual polar caps to determine the composition, seasonal variations in surface temperature, and depth of the condensed volatiles is the most straightforward approach to this question. But the seasonal variation in total atmospheric mass is also an important clue. If this variation is very small, less than about 1/3 mb, then winter storage of CO_2 is unlikely to be adequate to maintain a permanent cap against sublimation during the summer. If the annual variation in pressure is much larger, a stable solid CO_2 reservoir may exist, depending on the albedo of the residual cap.

I.6. Is There Life on Mars?

A key element in comparative planetology is the distribution of life in the solar system. Mars is the only planet other than Earth with current conditions and likely natural history consistent with the origin and evolution of earth-like life; i.e., organisms based on protein-nucleic acid systems. Hence, if the generalizations about the composition of terrestrial life are universals of biology, the search for extraterrestrial life should focus on the planet with physical conditions compatible with stability and function of protein-nucleic acid systems and with a natural history conducive to the pre-biotic chemical evolution of proteins and nucleic acids. If Martian life exists, it should be most readily detectible by measuring changes in the chemistry in a closed system in which Martian life is propagated. Chemical change in the environment caused by extraterrestrial life is less conjectural than the chemical composition of the putative extraterrestrial organisms. The importance of subsequent questions obviously depends upon the answer to this question; thus, the questions which follow are explicitly conditional.

1.7. If Life Exists on Mars, What is its Composition, Structure, and Function?

From the previous discussion it is obvious that the key question is whether genetic information is contained in nucleic acid(s) and expressed by the catalytic properties of proteins; and this is a technically difficult question because wet chemistry will be required for definitive answers. Structure can be determined by (microscopic) imaging of propagated Martian life. Function can be assessed by measuring changes in the chemistry of closed systems in which Martian life is propagated.

I.8. If Life Does Not Now Exist on Mars, Are There Either Chemical Fossils or Accumulated Products of Pre-biotic Chemical Evolution?

These two questions are conjoined because the organic chemicals expected from pre-biotic evolution (amino acids, purines and pyrimidines, fatty acids, sugars, etc.) are closely similar to those expected in fossils. Distinguishing between the two possible origins of such substances would require more subtle measurements than detecting their presence. Although to the biologist, the detection of chemical fossils would be more significant, even the detection of such compounds would constitute a discovery of the first magnitude.

CHAPTER II

MARINER 9 SCIENTIFIC ACCOMPLISHMENTS

The Mariner 9 orbiter provided a platform for 6 different instrument-oriented investigations: television imagery, infrared radiometry, infrared spectroscopy, ultraviolet spectroscopy, radio occultation analysis, and celestial mechanics from spacecraft tracking data. The objectives of these complementary investigations were to provide extensive information for detailed studies of both fixed and variable properties of Mars. Specifically, the goals can be summarized as follows: to characterize the geological structures and to map their distribution over the planet, to identify processes responsible for modifying the surface, to determine the nature of time variations in surface albedo, to investigate the composition, temperature distribution, cloudiness, and dynamics of the atmosphere, including time variations, to characterize the shape and gravity field, and to survey the satellites. The orbiter was not expected to provide information directly relevant to the question of the existence of Martian life beyond adding to knowledge of the Martian environment. These goals were largely achieved, and the findings have greatly advanced our understanding of the planet. They have also raised new questions. We summarize here what we believe to be the major new findings, and some of the major new questions.

II.1. Internal Processes

The Mariner 9 pictures showed that the surface of Mars is much more varied than that of the Moon. Large areas are heavily cratered, like the terrain identified by Mariner 4, but the Mariner 6 and 7 findings both of smooth basins, and of "chaotic terrain" - terrain formed apparently by systematic removal of underlying material and slumping of surface material - were confirmed. The latter was found to be contiguous with an extensive system of flat-floored steep-sided valleys and canyons whose scale is enormous. One of the most exciting discoveries was that of earth-like volcanic features: volcanic domes and shields, calderas, lava flows, and collapsed lava tubes. Although no objects of this type were identified from earlier spacecraft, these features cover large areas and are in some cases very spectacular. Nix Olympica, for example, is much larger than any terrestrial volcano. There is a large range in apparent age of the volcanic features (based on crater abundance and other evidence for modification), but many of them seem relatively young, indicating that some melting has taken place in Mars' interior over a long period of time, as well as in the recent past. It may still be going on. Consistent with these observations, the airborne dust was found to have a high silicate content, indicative of a considerable degree of differentiation.

There is abundant morphological evidence of vertical motion of parts of the crust, both upwelling and downwarping, but little or no evidence for the kind of lateral plate motions that occur on

Earth. Alignment of some of the volcanoes, their regional distribution, and their association with large-scale fault systems indicate that there are planet-wide variations in heat flow and melting, but the configuration and size of the volcanoes indicates that unlike such large terrestrial volcanoes as the Hawaiian Islands, they have remained stationary with respect to their underlying sources of heat. Apparently the Martian crust is much less mobile than that of the Earth. Mariner 9 extended our knowledge of the large-scale topographic variations, which were already known from earth-based radar observations to have very large amplitudes, and it showed that the Martian gravity field is also very rough. Evidently, the Mars crust supports much larger departures from isostasy than does the Earth's crust.

The Mariner 9 data have shown that Martian internal processes are earthlike in some aspects and very different in other aspects. But Mariner 9 did not explore many problems of the Martian interior and only began to explore others. For example, considering only problems which can be attacked by orbiters, it provided no information on internal magnetic fields, and no information on the composition of surface material other than the identification of a silicate component of the airborne dust. Because of the high periapsis altitude, gravity field measurements were limited to large scale components; the amplitudes of these indicate that the information contained in the smaller scale components could be very useful.

II.2. Surface Modification Processes

The Mariner results underscored the importance of aeolian processes. The spacecraft arrived when the usually visible features were obscured by a planet-wide yellowish veil, suspected of being a dust storm. Mariner confirmed that the obscuration was due to airborne dust, and showed that such very large-scale storms, as well as smaller and more frequent dust storms, play a major role in modifying the surface. The theory that time variations in light and dark markings can be caused by removal and deposition of dust carried by winds was confirmed, and the discovery of extensive sand dune fields showed that earth-like aeolian processes occur. There is evidence that large areas in the southern hemisphere are mantled by dust to depths sufficient to obscure even the largest craters in some places. In other areas, wind appears to have played a major role in scouring loose material from the floors of deep canyons and valleys. Elsewhere, it may have contributed to the shaping of extensive mesas and lowlands, the so-called "fretted terrain," possibly in combination with other processes such as sapping of ground ice. There is evidence that surface modification processes were more effective at some time during the past than they are now.

The principal question raised by the observations of surface modification is: to what extent have processes other than impact cratering, aeolian erosion, and deposition been responsible for modifying the surfaces? Ground ice sapping is a possibility. One of the most intriguing observations is that of canyons which look as though they have been shaped by water erosion. The very large scale of some of these features and their limited regional distribution pose serious problems for the water erosion hypothesis, but no satisfactory alternative has been proposed. At this point we are left with a puzzle having major geochemical and biological implications: has liquid water ever played a major role in modifying the surface of Mars? Answers to this question and other major problems of surface modification, such as establishing an absolute time-scale for these processes must come from future missions. Even in terms of geomorphological studies, Mariner 9 was limited in coverage at adequate resolution; only 2% of Mars was photographed at better than 1 km resolution.

II.3. Atmospheric Processes

Mariner 9 confirmed most of the Mariner 6 and 7 results on atmospheric composition, and extended these results to cover the whole of Mars and a considerable range of seasons. The only known components of the atmosphere are CO_2 and its dissociation products, CO, O_2, O, and C (the latter two occurring only in the upper atmosphere), together with water (vapor and ice), and ozone. The structure of the upper atmosphere, with undissociated CO_2 predominant, and the rate of thermal escape of hydrogen are similar to the structure and escape rate found by Mariners 6 and 7 in 1969, when allowance is made for solar cycle variations. Eventually, analysis of the Mariner 9 data will tighten the currently accepted upper limits on such candidate trace gases as N_2. First order estimates of the ratios of the relative abundances of CO_2 isotopes have been made from Mariner 9 spectral data; these ratios appear to be like those found on earth. Refined estimates of the N_2 concentration and the isotopic composition as well as the rare gas concentrations must await future missions.

Ozone and water vapor are variable constituents. Water vapor varies seasonally; its abundance is apparently related to both the planet-wide dust storms and the retreat of the polar cap. Ozone is closely related to temperature, its abundance increasing with decreasing temperature; it was undetectable in the tropics. Since the water vapor concentration is very sensitive to temperature, it has been inferred that ozone is controlled by water vapor through reactions with products of water photolysis. If this inference is correct, the Mariner observations may contribute to our understanding of ozone in the Earth's atmosphere where a similar mechanism is believed to operate.

The temperature distribution in the lower atmosphere was strongly affected by the planet-wide dust storm; the airborne dust absorbs solar radiation, heating the atmosphere and cooling the surface. The dust heating provides a powerful feedback mechanism coupling solar heating to large-scale wind systems. Because of this, the occurrence of dust storms is quite sensitive to the magnitude and distribution of incoming solar radiation. Major features of the wind distribution could be determined from the temperature distributions observed by Mariner 9. These features included an intense thermally driven circulation, influenced by the dust absorption in the tropics and in the southern hemisphere (summer). The temperatures and cloud observations also showed that the middle and high northern and southern latitudes are dominated in winter by prevailing westerly winds and active baroclinic waves. The Martian atmosphere is sufficiently earth-like that observations such as these provide additional insight into processes occurring in our own atmosphere. In addition, the circulation is a key element in several problems in Martian planetology: how are the volatiles CO_2 and H_2O stored and transported each season? Why are there apparent regional differences in aeolian modification of the surface? Mariner 9 provided clues to these questions, but did not provide sufficient atmospheric data to define the circulation over the Martian year.

Observations of the polar regions raised new and important questions. Evidence for aeolian erosion is particularly prominent in parts of both polar zones, but the central polar zones are dominated by deep laminated deposits. These are suspected of containing large amounts of frozen volatiles, including water and possibly carbon dioxide, as well as dust. If large reservoirs of volatiles do exist at the poles, there is a real possibility that Mars may have had very different climatic regimes in the past than it has now. For example, if the polar regions were once warmer than now, the stored volatiles could have resided in the atmosphere, with the result that a warmer and moister climate might have prevailed. This possibility is particularly tantalizing in view of the observation of erosional features resembling channels formed by running water. The questions of whether there are large reservoirs of CO_2 and H_2O, and whether substantially larger amounts of these gases ever resided in the atmosphere are of great importance for understanding the history of Mars. In view of recent speculation on long term variations in solar luminance, and of the dependence of the atmospheric mass on solar luminance if volatiles reservoirs exist, answers to these questions could also bear on the problem of long-term solar variations. <u>In situ</u> measurements of composition of the residual polar caps may be the most direct way of resolving the reservoir problem.

CHAPTER III

ANTICIPATED VIKING 1975 SCIENTIFIC ACCOMPLISHMENTS

The Viking missions are designed to significantly advance the knowledge of Mars by direct measurements in the atmosphere and on the surface and also by observations of the planet during approach and from orbit. Particular emphasis will be placed on obtaining information concerning biological, chemical, and environmental factors relevant to the existence of life on Mars at this time, at some time in the recent past, or the potential for the development of life at a future time.

III.1. Viking 1975 Scientific Investigations

Two Viking spacecraft will be sent to Mars to arrive in the summer of 1976. Each spacecraft will consist of a lander and an orbiter. The Martian season at the time of arrival will be spring equinox in the Northern hemisphere. Thirteen investigations will be carried on each of the identical spacecraft. Three of these will be on the orbiter, one will be done during the entry into the Mars atmosphere, eight will be done on the lander, and one will utilize the telecommunication systems. These investigations are listed in Table III-1.

III.2. Direct Biology

Viking is the first U.S. opportunity to begin the direct search for extraterrestial life on Mars. Ultimately, this discipline will lead to understanding the place of Mars in the organic-biochemical-biological

TABLE III-1

VIKING 1975 SCIENTIFIC INVESTIGATIONS

	Experiment	Instrument	Sensitivity	Objective
Orbiter	Orbital imaging	2 TV cameras	40m/TV line	Certify and monitor landing sites - obtain other planetary coverage
	Water mapper	IR spectrometer	1-20μppt.H_2O, ±1μ	
	Thermal mapper	IR radiometer	±1° at 200°K	
Entry	Entry science	Upper atmos. M.S. R.P.A. Temp.; press.	1-50 mass units 10^{-13} amps ±4°K; 1-20mb, ±0.3mb	Atmospheric chemical and physical profile
Lander	Imaging	2 Facimile cameras	360°, color, .04° (H.R.) angular resolution	Characterize landing sites
	Biology	Metabolism, photosynthesis	----	Direct test for life
	Molecular analysis organic atmospheric	 GC/MS MS	 10-100 ppm	 Surface organic chemistry Atmospheric composition
	Inorganic chemistry	X-ray fluorescence	A few percent	Surface inorganic chemistry
	Meteorology	Wind velocity Press., temp.	12m/sec 0.5mb; ±9°K	Meteorology at surface
	Seismometry	Seismometer	50×10^{-6}mm at 1Hz	Seismic activity, internal structure
	Magnetic properties	Magnet & magnifying mirror	----	Surface processes, composition
	Physical properties	----	----	Surface processes
Radio	Radio Science	Telecommunication system (2 GAZ and 8 GHZ)		Atmospheric composition, relativity studies

chain of events. The direct biology instrument on Viking 1975 has three component experiments: pyrolysis, label release, and gas exchange. In the pyrolysis experiment, a Martian soil sample is incubated with $C^{14}O_2$ and $C^{14}O$, with provisions made for illumination and addition of water vapor. Following incubation and flushing out of unreacted gases, the organic matter is liberated by pyrolysis and the amount of C^{14} contained therein is indicative of synthesis of organics from CO_2 and/or CO. The label release experiment involves the incubation of a sample with a medium containing C^{14} labeled organics. The appearance of radioactive gaseous products (primarily $C^{14}O_2$) in the headspace is evidence for the presence of degradative metabolic processes. In the gas exchange experiment, soil is incubated with medium containing unlabeled organics and the headspace is monitored for H_2, N_2, O_2, CH_4, and CO_2 by gas chromatography. Changes in gas composition will be suggestive of metabolic processes.

The analyses performed on Viking are planned to provide a specific demonstration of life, despite clearly understood potential ambiguities. The positive discovery of extraterrestrial life would thrust the planetary program into an entirely new realm having far reaching effects on the Nation's space goals. The absence of any specific demonstration would be inconclusive. Numerous reasons could be postulated for such a negative answer, e.g., lack of sufficient sensitivity, incorrect assumption of Martian biochemistry, localized habitats, restricted time of biological activity, mismatch of terrestrial analogies or, indeed, no contemporary life. It is clearly not possible to demonstrate the last alternative with one pair of spacecraft.

In addition to the direct biology experiments, an organic analysis experiment is included on Viking and is intended to determine first order levels of identification of classes of organic molecules, biological as well as non-biological. Not considered to be a "life detector" by itself, the organic analysis is likely to provide strong clues to the biological question and to aid in the design of future experiments. Low levels and simple types of organic compounds will shed little light on the biology of Mars, but will tell us something of possible evolving neo-organic systems. Large concentrations of complex (biologically important) molecules will be suggestive of biological activity; and, of course, there is a spectrum of possibilities between these two extremes. Although the organic analysis is a significant complement to the biological experiments, it will be of more direct importance to our understanding of organic chemical evolution on Mars (in the presence or absence of life).

Without exception, all environmental data returned from the planet bears on the biological question (which requires detailed measurements of the physical and chemical character of the planet).

Viking is then our first attempt, with long odds but for great rewards, to determine whether the hypotheses about Martian life are correct.

III.3. Atmospheric Science

The entry experiments will provide composition and temperature profiles through the atmosphere. This should be sufficient to answer first-order questions concerning upper atmosphere photochemistry and radiative distributions of heating and cooling. The orbiter MAWD (Mars Atmospheric Water Detector) experiment will define the planetary distribution of water vapor and temporal changes. Unfortunately, there will be no direct determination of water vapor circulation, because there is no thermal sounding experiment from which flow can be deduced. The meteorology experiments on the lander will measure wind, temperature, and pressure. A time record of conditions at two points on the planet will thus be well defined, during one Martian season. This will provide essential ground truth needed for interpretation of data bearing on circulation obtained by orbiters other than Viking. The orbiter TV cameras will show cloud formations which we know from Mariner 9 experience can provide much qualitative information concerning circulation and which are of interest themselves. The major lack, as far as Viking and atmospheric science are concerned, is global coverage of thermal structure variations and of ozone variations.

III.4. Geological Science

Viking will provide us with our first "on the ground" view of Mars. A trio of geological investigations will explore three critically important subjects: the morphology of the surface, the chemistry of the soil, and the physical structure of the interior. Lander pictures will provide information regarding those processes which are (or were) important in modifying the surface: eolian erosion and deposition, meteroid impact comminution, vulcanism, and fluvial activity. The inorganic analysis by X-ray fluorescence techniques will directly determine the major elemental composition of surface materials. By interpretation it will provide clues regarding crustal composition and the degree of differentiation, either by igneous processes or by chemical weathering. The seismic investigation will supply information concerning the frequency and magnitude of "Marsquakes" and possibly data regarding Mars' internal structure. Detailed pictures of large areas taken from the orbiter and coupled with IR radiometer data will provide a view of the surface significantly better than that which Mariners have obtained. Lander investigations will provide the "ground truth" points required for a rational extrapolation of data obtained from these orbital pictures.

III.5. Magnetic and Physical Properties of Surface

Using a magnet, a magnifying mirror, and photography, it will be possible to determine the presence or absence of ferromagnetic particles on the surface. Combining this with other data, some general ideas of the state of oxidation can be learned. Physical properties, a clue to formative processes, can be inferred by measuring the force required during soil digging, observing the landing "foot prints," and performing rock-drop tests with the sampling arm.

Knowledge of the geochemistry of Mars is fundamental for developing its history. A principal investigation that is not being performed is the determination of the minerological composition from which to make more conclusive deductions leading to understanding the thermal events and other planetological crustal phenomena.

III.6. Radio Science

Data from the radio and radar systems are to be used to make determinations of the Mars gravitational field, axis of rotation, ephemeris, shape of the planet, atmospheric structure, ionosphere, the natural satellites, and surface properties. It will also aid in locating the lander, performing relativity studies, and in studying the interplanetary medium and the solar corona.

III.7. Viking 1975 "Non-findings"

The previous sections of this Chapter have dealt mainly with the scientific objectives of the investigations which form the payload of the Viking 1975 mission. It should be noted, however, that there are certain measurements which Viking will not be making or which can be improved upon. These "non-findings" were considered during development of the post-Viking exploration strategy. Examples include: no magnetic field measurements, limited upper atmosphere mass spectrometry, limited seismometer range, absence of atmospheric thermal mapping, no low orbit gravity measurements, no near IR data from orbiter, limited surface geochemistry, and limited biosensitivity.

CHAPTER IV

MARS MISSION OPTIONS AND CAPABILITIES

The planetary advanced studies program has included a study of the Mars mission options following the 1975 Viking Orbiter/Lander Mission. In formulating a Mars exploration program in the post-Viking era, the mission options have been extensively reviewed and this chapter of the report summarizes the essential results of the studies. The Mars mission options considered are given in Table IV-1. Short descriptions of each option are presented in Appendix I. In addition, an overview and assessment of the on-going Supporting Research and Technology (SR&T) in the scientific disciplines which support the objectives of the Mars Exploration Program are presented in Appendix II.

IV.1. Mission Analyses

Launch opportunities to Mars occur approximately every two years. The earth launch energy (C_3 - km^2/sec^2) required for each opportunity from 1975 through 1988 is shown in Fig. IV-1. For reference, the Viking 1975 requirement is indicated. Attendant with the earth launch energy is the approach velocity of a spacecarft at Mars. This data, shown in Fig. IV-2, is a key influence in performing the tradeoffs relevant to orbital sizing. Missions to Mars designed to enter and land on a direct trajectory would have to be designed to meet the direct entry velocity requirements shown in Fig. IV-3.

TABLE IV-1

MARS MISSION OPTIONS

Orbiters	Pioneer long-life Mars Orbiting Scientific Station (MOSS) Viking long-life
Probes	Capsule System Advanced Development (CSAD) Penetrometer
Landers	Viking Viking plus tethered rover Autonomous rover
Sample return	Mars
Satellite missions	Phobos/Deimos

The size of spacecraft delivered to Mars in any given opportunity is a function of the launch vehicle capability. For purposes of this report, the following stable of launch vehicles has been assumed:

1. Titan III E/Centaur, 1974-1984.
2. Shuttle/Centaur or Shuttle/Dual Transtage, 1981-1986.
3. Shuttle/Recoverable Tug, 1984-1988.

Graphs of the earth injected payload mass to Mars for the assumed stable of launch vehicles are shown in Fig. IV-4. For an orbiter mission, the injected payload must include a retro propulsion system to brake the spacecraft into the desired Mars orbit. The size of the propulsion system is a function of the spacecraft mass and orbit characteristics. For a synchronous orbit at Mars such as Viking is planning (24.6 hr period) the approximate mass that can be inserted by the assumed stable of launch vehicles is given in Fig. IV-5. Shorter period orbits will reduce the net mass in orbit.

For Mars lander missions, latitude accessibility is a key planning element. The range of latitudes accessible for nominal launch conditions, assuming landing occurs at least 15° from the terminator and considering no apsidal rotation, is shown in Fig. IV-6 for the launch years of interest. Areocentric latitudes of the sun and earth are indicated in the legend.

The landed payload mass is constrained by many interrelated mission analysis factors. Predominant among these factors are entry velocity, aerodecelerator performance, terminal descent propulsion performance and the desired landing velocity. Design parameters such as Lift/Drag ratio, parachute diameter and aeroshell diameter are traded to optimize landed weight. Entry velocity is reduced by several km/sec below that shown in Fig. IV-3 for out-of-orbit entry. This contributes toward increased landed weight.

Of the mission options considered, sample return from Mars is the most demanding from an energy viewpoint. The landed weight on Mars must include the capability to lift-off from the surface and return to earth. Velocity requirements for Mars departure and earth arrival are shown in Fig. IV-7. Sample return spacecraft from Mars must be designed to accommodate these velocities. At earth arrival, the return system can be inserted into earth orbit for recovery or it may enter on a direct entry trajectory.

Numerous Mars missions are possible in the post-Viking era. With the advent of the Shuttle in the 1980's, Viking-class payloads can be delivered to Mars during the high energy years 1983-1986.

IV.2. Building Blocks for Mars Exploration

An essential requirement in the development of an exploration program is to arrange a mission set so that the information acquired from one mission can be used to develop objectives for succeeding missions. This desire to maximize scientific feedback must, however, be modulated by the realities of celestial mechanics, launch vehicle capabilities and fiscal constraints. Consideration of these elements in program development leads to the philosophy that specific missions should be accomplished with a minimum number of spacecraft building blocks. Maximum utilization of existing spacecraft is required, with technological advancement occurring in an evolutionary manner from mission to mission.

Two basic building blocks now exist for future Mars exploration: the Mariner family and the Viking Orbiter/Lander. Mariners 4, 6 and 7 have completed flyby missions and Mariner 9 recently completed a 1 year orbital mission. The Viking is scheduled to orbit and land in 1976.

Other potential building blocks for a Mars program are the Pioneer Venus spacecraft, the CSAD (Capsule System Advanced Development) capsule and the semi-autonomous rover. These building blocks are in varying states of development, ranging from technical feasibility studies to feasibility hardware models.

This composite of building blocks forms the bases for the development of an extensive and cost-effective program of Mars exploration.

a. The Mariner Family

Mariner is a generic name for a series of spacecraft that have been flown to Mars and Venus and are currently scheduled to go also to Mercury, Jupiter and Saturn. Mariners are three-axis stabilized spacecraft, capable of carrying sizeable science payloads and precisely pointing the instrumentation. During critical orientation periods, gyro stabilization is provided. Other features include high data rates and storage, programmable on-board computers and excellent navigation performance, through the combined use of radio and on-board optical measurements. The initial Mariner to Mars was launched on November 28, 1964. This was followed by two successful flybys of Mars, Mariner 6 and Mariner 7, on July 31, 1969 and August 5, 1969, respectively.

The missions of Mariners 6 and 7 was focused on obtaining information about the Martian surface and atmosphere. No cruise instruments were carried and the Mars encounter science instruments, weighing 59 kg and mounted on the steerable scan platform, were: (a) wide-angle and narrow angle TV cameras, (b) infrared radiometer, (c) ultraviolet spectrometer and (d) infrared spectrometer. The spacecrafts closest approach at Mars was approximately 3220 km and the wide-angle and narrow-angle TV cameras showed areas of Mars about 1000 × 1000 km (details approximately 3 km) and 100 × 100 km (details approximately 300 m), respectively.

Mariners 6 and 7 weighed 380 kg, communicated 2000 times faster than Mariner 4 at a maximum bit rate of 16,200 bps and had the ability to store 1.8×10^8 bits of data. A major new feature of these spacecraft was the use of a programmable computer on board, with a memory capacity of 128 words. Actual lifetimes of the spacecraft were 1.8 yrs and 2.2 yrs, respectively.

These missions were succeeded by Mariner 9 which was inserted into a 12 hr orbit on November 14, 1972. 70 kg of instruments were carried on-board the 435 kg spacecraft (excluding retro propulsion), including: (a) wide-angle and narrow-angle TV cameras, (b) infrared radiometer, (c) ultraviolet spectrometer and (d) infrared interferometer spectrometer. Mariner 9 transmitted 7,329 TV pictures of Mars and Phobos and Deimos during its orbital lifetime of 349 days. A complete photographic map of Mars was obtained and the total science data received from Mariner 9 exceeded the total from the three previous Mariners by a factor of 25. Data rates and storage capability were similar to Mariners 6 and 7. A photograph of Mariner 9 is shown in Fig. IV-8.

b. 1975 Viking Orbiter/Lander Mission

The National Aeronautics and Space Administration is scheduled to launch two spacecraft to Mars in 1975 to orbit the planet and soft-land on the surface to significantly advance knowledge of the planet with emphasis on determining if life once existed, is present, or might develop.

The previous Mariner Mars flights have supplied most of the Martian data which permit us to plan and design the Viking mission. These data include atmospheric composition, atmospheric structure, surface elevations, atmosphere and surface temperatures, topography, figure of the planet, and ephemeris information.

Mariners have also supplied much experience in conducting an orbital mission, inserting a spacecraft into planetary orbit, and processing large quantities of digital data. The design of the

Viking orbiter is based on the Mariner spacecraft, with many of the subsystems being nearly identical.

In separate launches spaced at least 10 days apart, two Titan/ Centaur launch vehicles will lift off from Cape Kennedy and initiate the Viking journey to Mars. Shortly after separating from the Centaur, the orbiter orients and stabilizes by using the sun and Canopus for celestial reference.

During the journey, trajectory flight path corrections, if needed, will be based on navigation information acquired from earth-based tracking and performed by firing the orbit-insertion engine.

The orbiter, powered by a combination of solar panels and batteries, will furnish electric power to the lander until they separate at the planet. The lander has a set of rechargeable batteries which will be charged during Mars surface operations by two radioisotope thermoelectric generators (RTGs).

Information concerning flight performance is transmitted to earth throughout the flight. An onboard orbiter computer controls all spacecraft operations and supplies commands for trajectory corrections. Communication with Viking will take longer and longer as the spacecraft gets farther away from earth. At Mars, a round trip minimum of 40 minutes will pass. For this reason, automation is essential. Operations that cannot be interrupted, such as the soft landing, will be performed completely automatically by an onboard preprogrammed computer.

As the spacecraft nears the planet (each spacecraft arrives at a different time), it is maneuvered into the proper attitude for being placed in orbit. The engine will be fired for nearly an hour to place the combined orbiter and lander in a highly elliptical orbit of 1,500 km by 33,000 km which has a period of approximately 24 hours to match Mars' period of rotation.

The spacecraft will be tracked for at least 10 days after achieving orbit to get detailed information necessary to achieve a precise landing as well as check out preselected landing sites. Mission controllers will have a total of 50 days, if necessary, to further study the planet to confirm optimum landing sites.

The first Viking lander is scheduled to land on July 4, 1976. The prime landing site is in the region called Chryse near the north-east end of the vast 5,000 km rift canyon that makes a reverse S-shaped curve across the Martian Equator. Coordinates of the site are 19.5°N and 34°W. The second prime landing site is in the location called Cydonia. It is at the fringe of the cloud bank that hides the Martian northern polar cap during winter. The Cydonia coordinates are 44.3°N and 10°W.

When the landing sequence is initiated, the lander's power is turned on, and the lander within its aeroshell separates from the orbiter. During descent and landing, the lander maintains communication with the orbiter, which serves as a relay station between the lander and earth. A parachute is deployed to further decelerate the lander at about 6,000 m above the surface. Shortly thereafter, the aeroshell is jettisoned. The parachute is jettisoned later, and the terminal propulsion system begins firing its three engines. The engines, firing 5 to 10 minutes, slow the lander for a soft landing and shut down just as the foot pads touch the surface.

The Viking lander science, weighing about 91 kg including 8 kg of science on the aeroshell, is divided into two areas of investigations; those made during the atmospheric entry phase prior to landing and those made on the Martian surface. Entry data will provide information on the upper atmosphere ion concentrations and composition and on the pressure, temperature, and density of the lower atmosphere. The lander science investigations and instruments are shown in Table IV-2.

While experiments are proceeding on the surface, the Viking orbiters will be passing overhead, observing the landing site so that local measurements made by the landers may be correlated with overall surface effects. Typical conditions to be searched for by the orbiters include the buildup of dust storms, variations in temperature and humidity, and the passage of the seasonal wave of darkening. The Viking orbiters each carry about 68 kg of instruments consisting of two high-resolution television cameras, an infrared spectrometer and an infrared radiometer.

The orbiter/lander spacecraft configuration is shown in Fig. IV-9. Mass of the orbiter is 730 kg exclusive of the retro propulsion system and science experiments. It has a minimum design

TABLE IV-2

LANDER SCIENCE AND INSTRUMENTS

Biology	3 Metabolic Analyses
Molecular Analysis	Gas Chromatograph and Mass Spectrometer
Imaging	2 Cameras (Stereo, IR, and Color Capability)
Meteorology	Pressure, Temperature, Wind, Sensors
Inorganic Chemistry	X-Ray Fluoresence Spectrometer
Seismology	3-Axis Seismometer
Magnetic Properties	2 Magnet Arrays and Magnifying Mirror
Physical Properties	Cameras, Sensors and Surface Sampler

lifetime of 16 months. Mass of the lander is 1006 kg at orbiter separation and 576 kg on the surface. Its design lifetime is 90 days. The Viking landed configuration is given in Fig. IV-10. More detail on the Viking mission, science and spacecraft characteristics can be found elsewhere (the Viking Missions to Mars, 1972).

The Mariner flights have provided the logical incremental steps in the exploration of Mars which had to precede Viking, just as Viking is a necessary prelude to eventual sample return, automated roving vehicles and possible manned missions to Mars.

c. Pioneer Venus Orbiter or Probe Carrier

Pioneer Venus building blocks for Mars missions will be based on the common spacecraft being designed for Venus. The Venus probe bus and orbiter spacecraft will be constructed by modifying the common design to match the requirements of each mission. Similarly, a Mars probe bus or orbiter can be constructed by modifying the Venus common design (Figure IV-11).

The Pioneer Venus program is about to begin the detailed design and construction of hardware. The program plans to receive Congressional approval in FY 1975 and launch two spacecraft to Venus in 1978. The program can be extended to launch a spacecraft to Venus during any future launch opportunity for follow on missions.

The Pioneer Venus missions will use a common spacecraft design. The common design is a spin stabilized, solar cell powered spacecraft. It includes power conditioning, attitude control, communications, data handling, structure, propulsion, and thermal control subsystems. For the Venus entry probe mission, the common design is modified by adding experiments, probe mounting hardware, antennas, and the entry probes. For the Venus orbiter mission, the common design is modified by adding experiments, a data storage unit, a solid propellant retro motor, and antennas (including a high gain despun antenna).

For Mars missions, the Pioneer Venus common design must be modified to function in the Mars environment. The modifications will include: increased solar cell area to provide the same amount of power and a changed thermal control subsystem to keep the spacecraft warm. For a Mars entry probe mission, the spacecraft will also need experiments, probe mounting hardware, antennas, and the entry probe. For a Mars orbiter mission, the spacecraft will need orbiter experiments, a data storage unit, a retro motor, and antennas.

Table IV-3 describes experiment support capabilities of Pioneer Venus spacecraft modified for Mars Missions.

The Mars orbiter spacecraft can use the same solid propellant retro motor as Venus orbiter missions. The Mars orbiter can benefit, however, from modest increase in the propellant load to reduce the orbit period. Figure IV-12 shows how increased retro propellant can be used to reduce the orbit period.

d. CSAD

In January of 1967, JPL undertook the design and development of a Mars planetary entry and landing system (JPL Document

TABLE IV-3. Experiment Support Capabilities of Modified Pioneer Venus Spacecraft

	Mars Entry Probe	Mars Orbiter
Experiment Weight	450 kg of Probes 15 kg on Bus	35 kg
Power	25W	52W
Spin Axis Pointing Accuracy	1^{o}	1^{o}
Data Transmission	400-2000 BPS	400-2000 BPS
Data Storage	-----	400,000 Bits

No. 760-29, 1968) designated Capsule System Advanced Development (CSAD). A functional feasibility model of the capsule was built and subjected to a series of functional and environmental tests, including heat sterilization and a simulated Mars landing impact test.

The capsule developed weighed 170 kg and carried the following science instruments: a mass spectrometer, an aeronomy package, a radiometer and water vapor detector to be used during atmospheric entry; a gas chromatograph, a meteorology package, including a wind instrument to be used on the planetary surface over one diurnal period. After heat sterilization, the lander survived impact tests which produced a vertical impact speed of 41 m/sec, the maximum expected during a Mars landing, and a g-level of 2500 g's.

The capsule descends to the surface on a parachute and collects and transmits real-time science and engineering data to the flyby or orbiter spacecraft until impact. Upon landing, the radio begins to transmit directly to earth wind, pressure, temperature and water vapor measurements, and an atmospheric compositional analysis. At the end of a designated period, the lander is turned off and re-activated the following day. In this design, lifetime is a function of battery capacity.

The CSAD is an example of a survivable impact probe that could be delivered to Mars for purposes of conducting specialized scientific investigation. The design characteristics of CSAD were sufficiently broad to incorporate the newly acquired knowledge of Mars.

e. Semi-Autonomous Rover

This potential building block has least amount of supporting technical detail, since only feasibility-level studies have been performed. From these studies (JPL Document No. 760-58, 1970), the prime characteristics of the semi-autonomous rover are: (a) mass - 500 kg. (b) surface lifetime - 1 year, (c) range capability - 1000 km and (d) science payload allocation - 50 kg.

The science payload might consist of imaging (both vidicon and facsimile), biology, inorganic and organic analysis, meteorology and seismometry. Several advantages of the rover are that it has the ability to escape the immediate (possibly contaminated) landing site, to scientifically explore many sites during its traverse, to reach specific localized areas of high interest, and to deploy small, independent science packages for specialized investigation at specified locations.

Delivery of the semi-autonomous Mars rover to the surface would be accomplished by a Viking-derivative landing system. Design of the rover would be such that "routine" decisions concerning path selection and control would be made on-board, without earth-based intervention, to efficiently operate during the large round trip communications time delay at Mars and the limited Mars-earth communication visibility periods. RTG power would be utilized to avoid the articulation and environmental problems likely to be encountered with solar panels. All motion control related functions would be integrated into a centralized control and data handling system.

IV.3. Mission Options

Table IV-1 listed some mission options which have been studied during development of strategy for the continued exploration of Mars following Viking 1975. Detailed descriptions of each mission option are presented in Appendix I. Included are details concerning mission objectives, launch vehicles, lifetimes, candidate payload instrumentation, weight constraints, and spacecraft characteristics and configuration. The capabilities afforded by each of these options in terms of the scientific objectives of Martian exploration were carefully considered in developing the strategy which is described in the following two chapters.

IV.4. Instrumentation

Future science return from Martian exploration will depend strongly upon the progress made in supporting Research and Technology (SR&T) programs aimed at advanced scientific instrumentation development. These programs play a key role in the formulation of science objectives which extend the expanse and depth of investigation at a particular target. Beginning with a base of instrumentation that was flown on Mariner 9 and which will be flown on the Viking mission, the existing SR&T efforts in planetary biology and planetology applicable to future Martian exploration were examined.

Appendix II contains descriptions of a number of biological and geological instruments which are being developed for future Mars missions under the existing SR&T program. Some of these efforts are devoted to improving the scientific return of existing instruments, while others represent new developments geared to answer new questions about Mars.

All of the instruments under development relate directly to many of the scientific objectives delineated in Chapter I. For example, SR&T funding in planetary biology is aimed at pursuing the life-organic compound questions. Viking will do the first generation analysis; that is, it can tell us if life and organic molecules are present. However, it will not provide a great deal of information on the nature and distribution of the life and organic molecules present. Therefore, second generation experiments are being developed which will characterize life forms, and which will identify the kinds and amounts of organic molecules found and determine their relationship, if any, to life processes.

Similarly, instrumentation under development in planetology includes one which is aimed at determination of the amounts and forms of water present in the surface and subsurface soil. This question, central to Mars exploration, is not being addressed directly on Viking 75. Other efforts are underway to expand and extend the limited inorganic analysis capability of Viking 75 in order to gain more knowledge about the formation and early evolution of the planet.

The SR&T instrument development programs in planetary biology and planetology described in Appendix II are responsive to many of the fundamental objectives of future Mars exploration. Following the definition of the scientific objectives of the next mission to Mars, a focusing of the SR&T efforts on readying instruments which will be most responsive to those objectives should be done.

IV.5. Mission Capability Summary

One mission constraint is related to the timing of new launch vehicle and upper stage development and the type of missions desired in a particular time frame. As shown in Section IV.1., the energy requirements for launch and arrival vary considerably over the period of interest. Thus, as the launch and arrival energies increase, a given launch vehicle injects less payload toward Mars and a given spacecraft propulsion capability inserts less mass in Mars orbit or lands less mass on the surface. The mission and spacecraft design must consider these factors in the tradeoff process and the practical limitations they impose. A specific example of how the energy requirements at Mars affect design is a comparison of the 1979 and 1981 opportunities. In 1979, a duplicate Viking 1975 Mission can be flown using a Titan IIIE/Centaur with a lander payload margin of about 100 kg; whereas, in 1981, the orbiter propulsion system has to be significantly increased for the same mission design. Conditions as applied to a duplicate Viking mission degrade rapidly until the 1988 opportunity.

More capable launch vehicles and upper stages will aid in overcoming the energy limitations. This will allow more injected mass toward Mars, part of which can be allocated to the spacecraft for compensation (retro propulsion, deceleration devices, etc.) of the high energy requirements. The Space Shuttle is planned for operation in the early 1980's, but the definition and schedule of development of an upper stage is at present unclear. With the increase in payload capability of the Shuttle/Centaur, missions of the Viking-class are feasible. With the Titan IIIE/Centaur, Viking-class missions are not feasible and the mission possibilities will be limited to lower-mass orbiter and probe missions.

Major new technology programs do not appear to be required for implementing the prospectus of future Mars missions. This, however, does not eliminate the need for technology advancement and possible reorientation. Missions such as the sample return will require technology emphasis in such areas as aerodeceleration, Martian surface ascent control and rendezvous and docking (if required).

REFERENCES TO CHAPTER IV

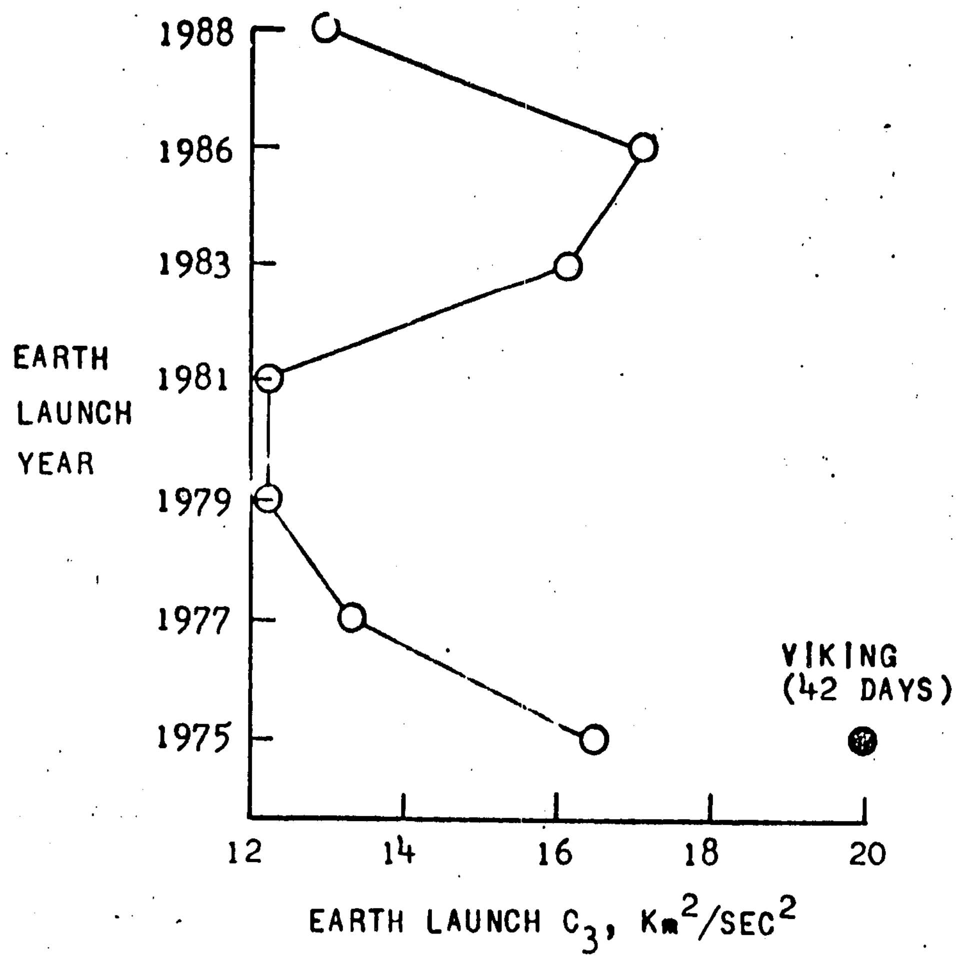
JPL Document No. 760-29, 15 July 1968, "Capsule System Advanced Development Program Report."

JPL Document No. 760-58, 1 Dec. 1970, "An Exploratory Investigation of a 1979 Mars Roving Vehicle Mission."

The Viking Missions to Mars, Icarus 16, 1972.

FIGURE IV-1

EARTH - MARS LAUNCH ENERGY REQUIREMENTS
(30 DAY LAUNCH WINDOW)



FIRST LAUNCH DATE

6/20/88

5/07/86

12/07/83

11/09/81

10/14/79

9/20/77

8/25/75

FIGURE IV-2

APPROACH VELOCITY REQUIREMENTS

(30 DAY LAUNCH WINDOW)

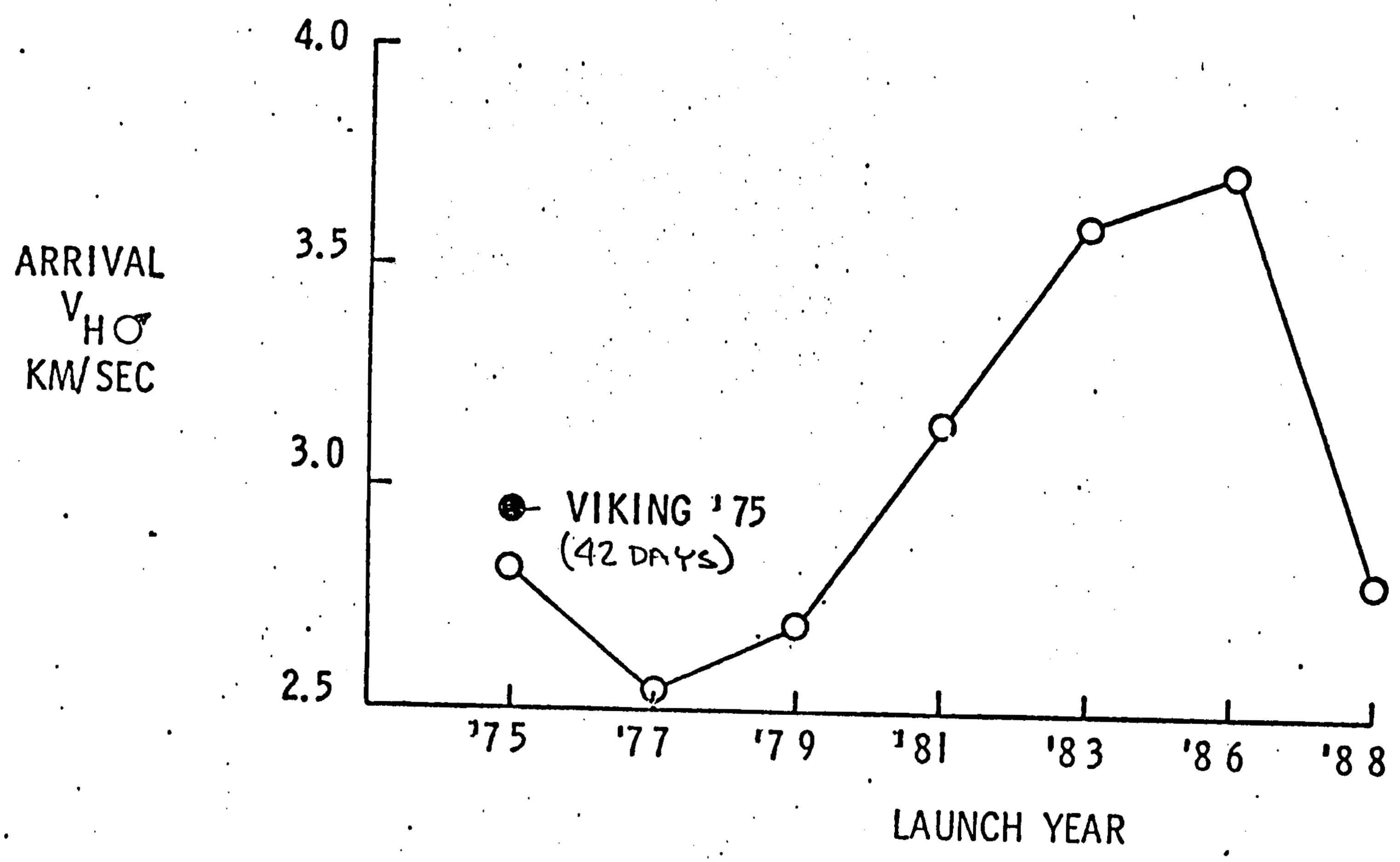


FIGURE IV-3

DIRECT ENTRY VELOCITY REQUIREMENTS

(30 DAY LAUNCH WINDOW)

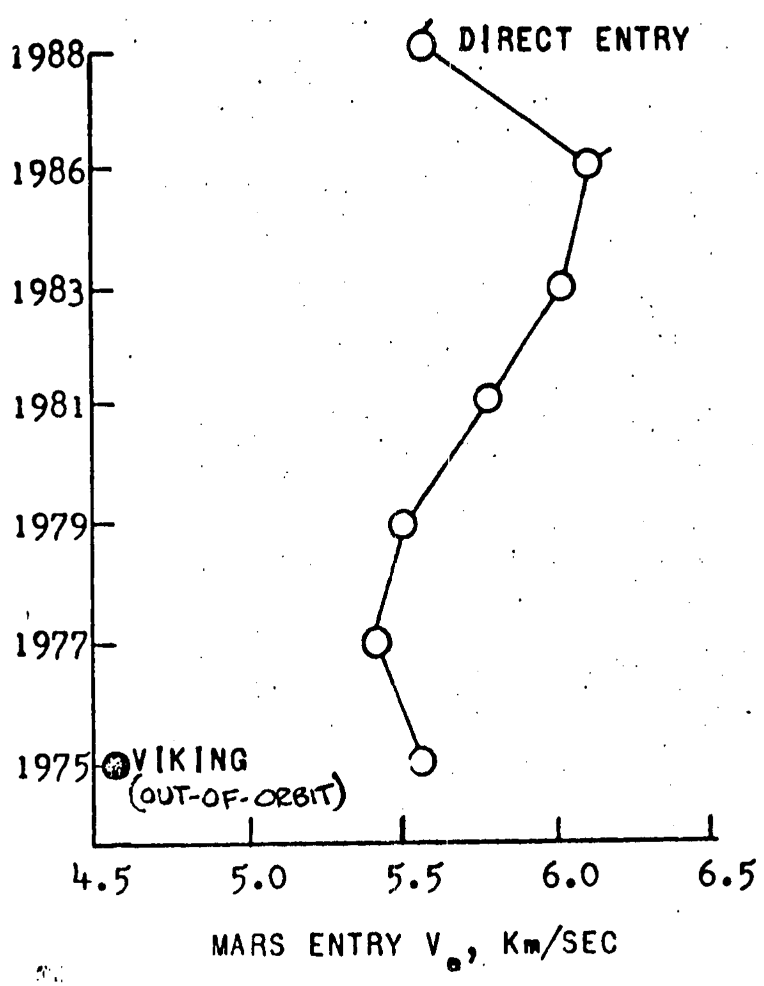


FIGURE IV-4

LAUNCH VEHICLE CAPABILITY
(30 DAY WINDOW)

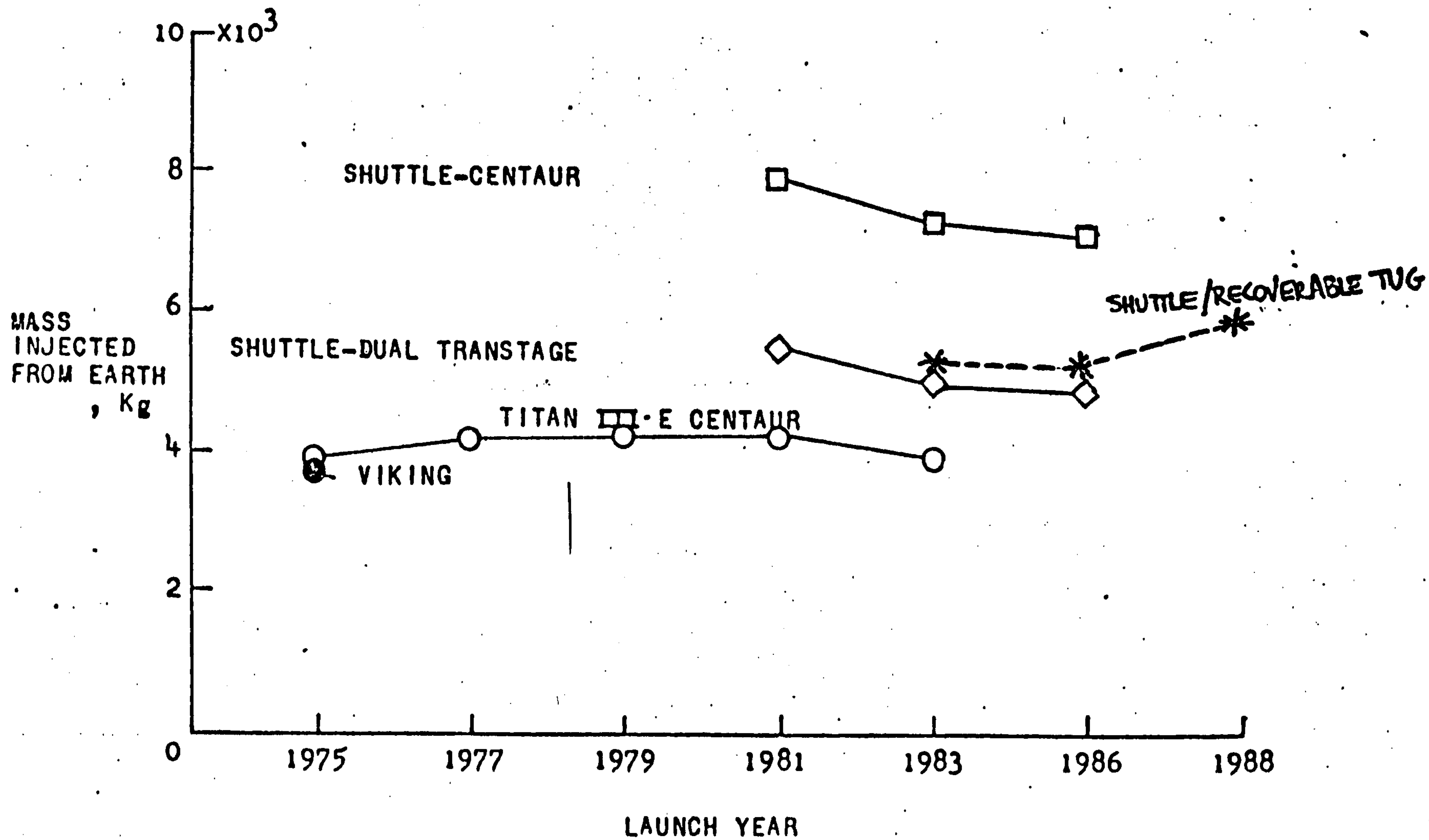


FIGURE IV-5

MASS IN MARS ORBIT

(SYNCHRONOUS ORBIT – VIKING)

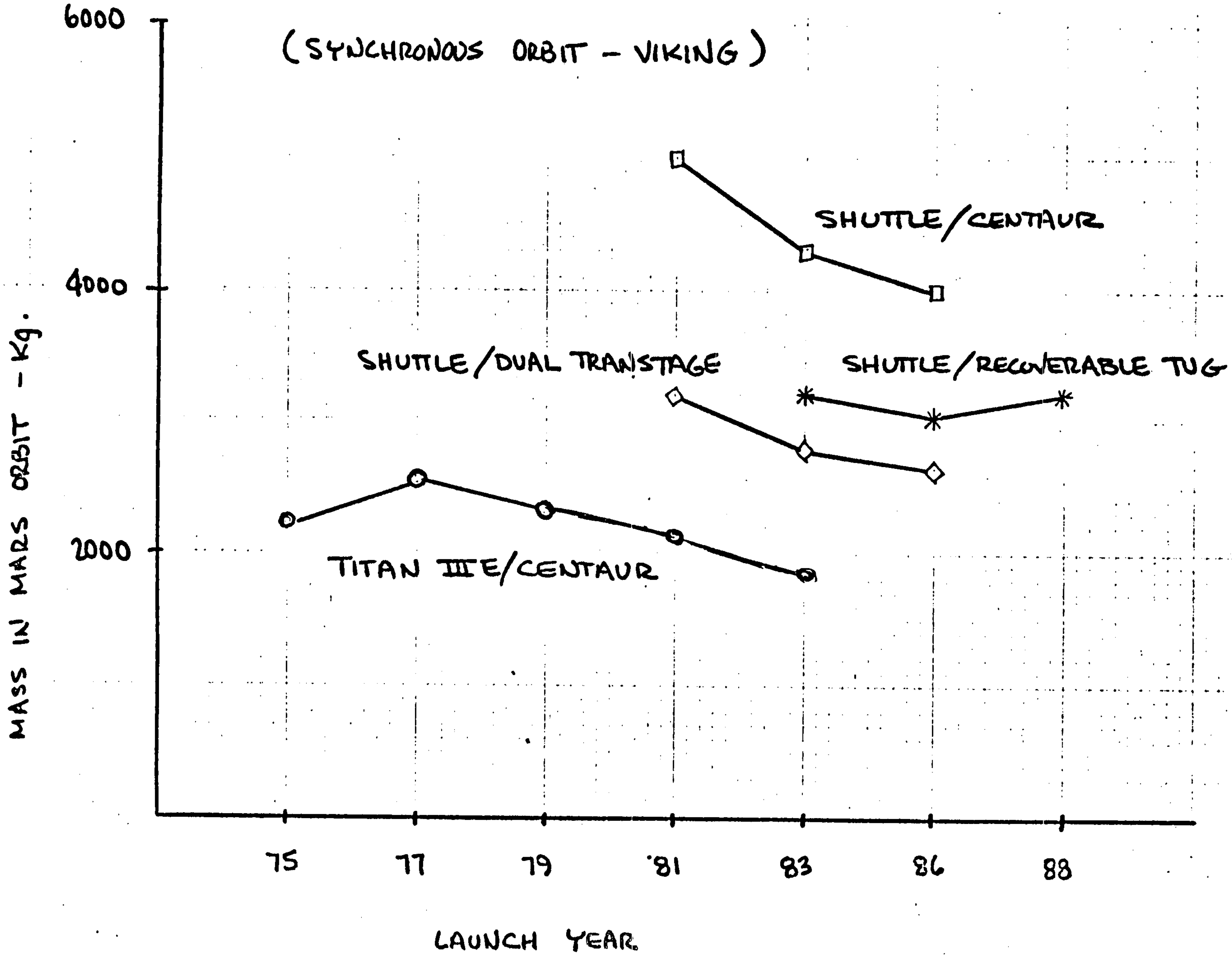


FIGURE IV-6

LANDING SITE LATITUDES FOR NOMINAL LAUNCH
(15° from terminator, No apsidal Rotation)

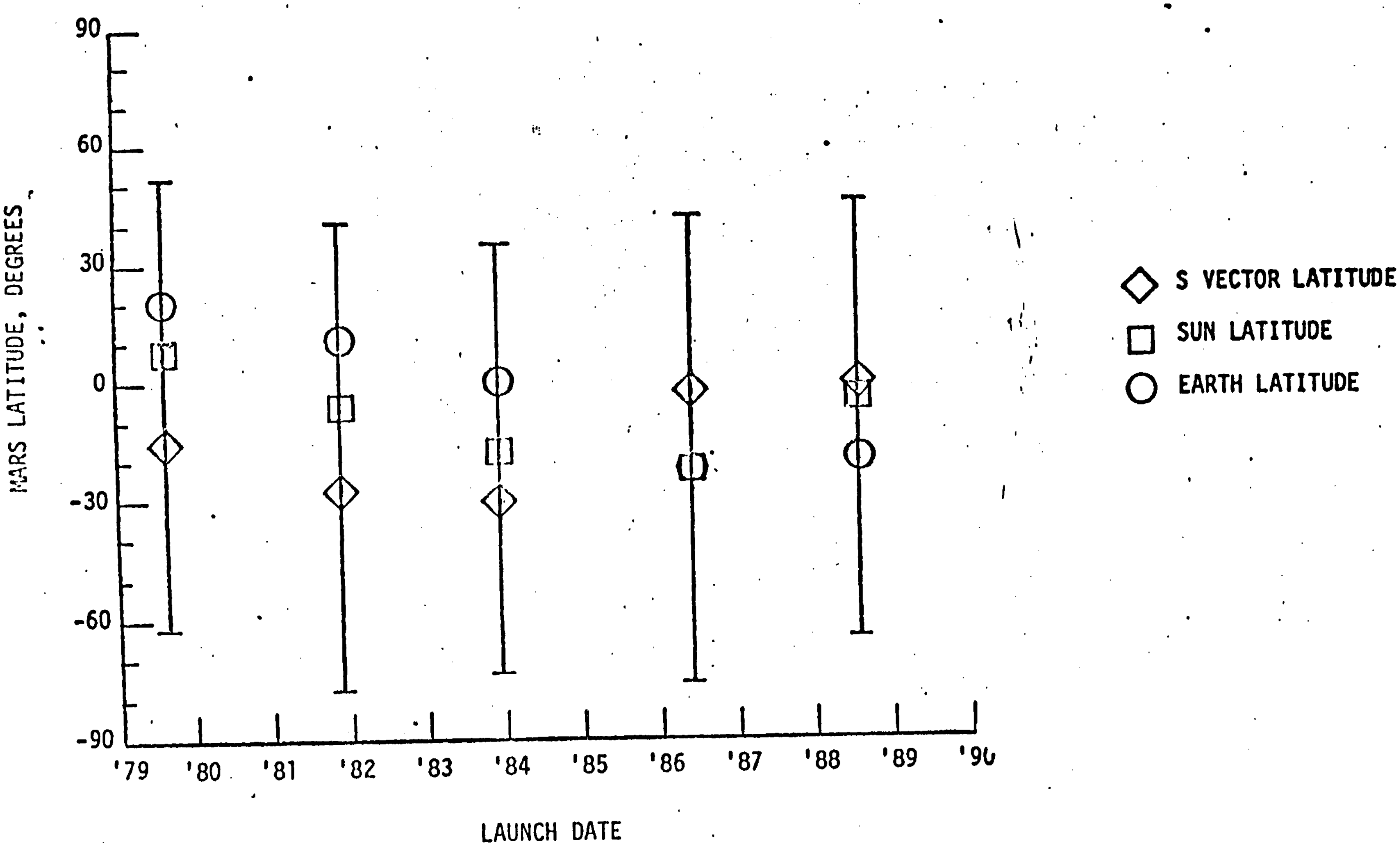
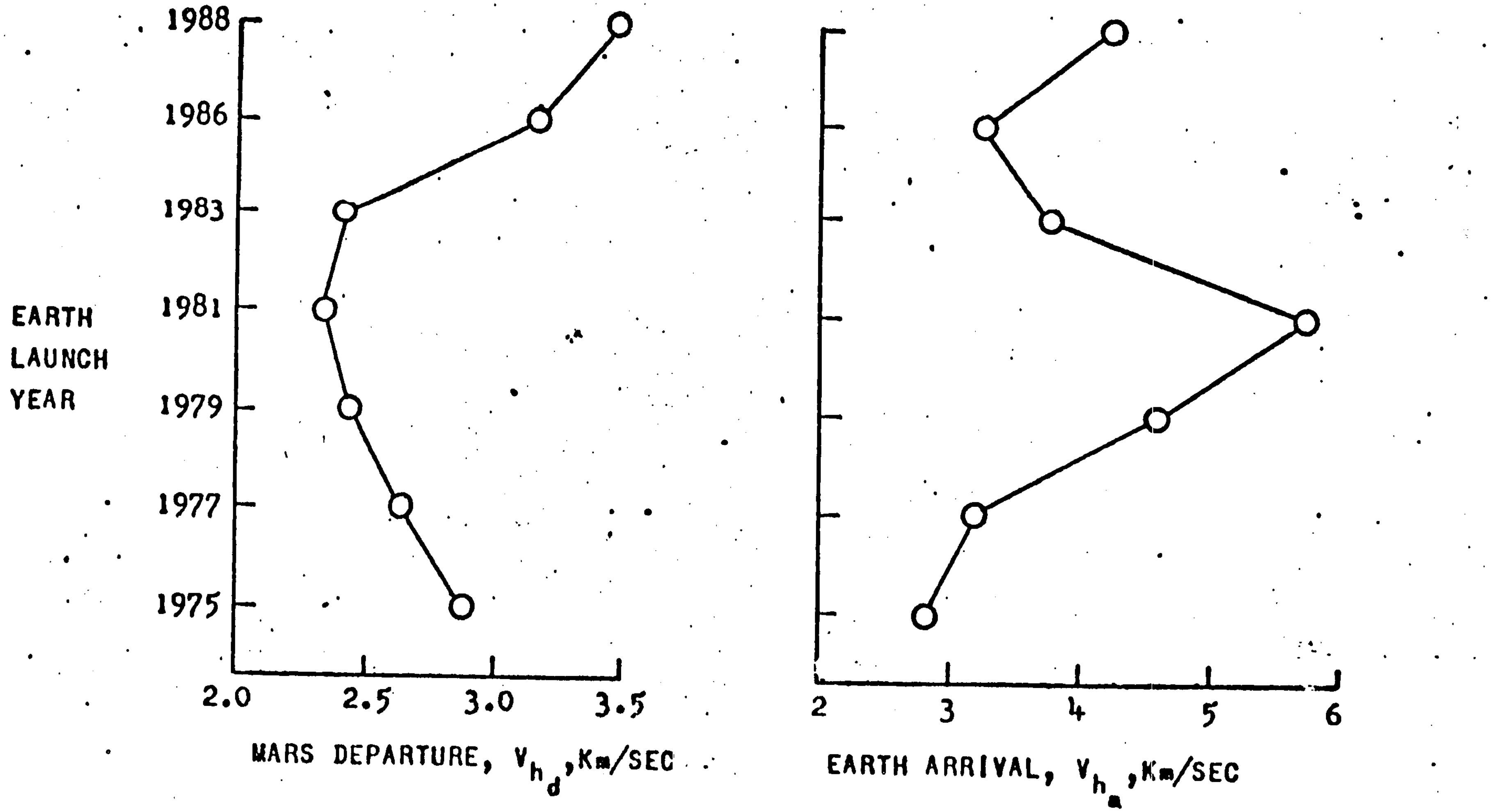
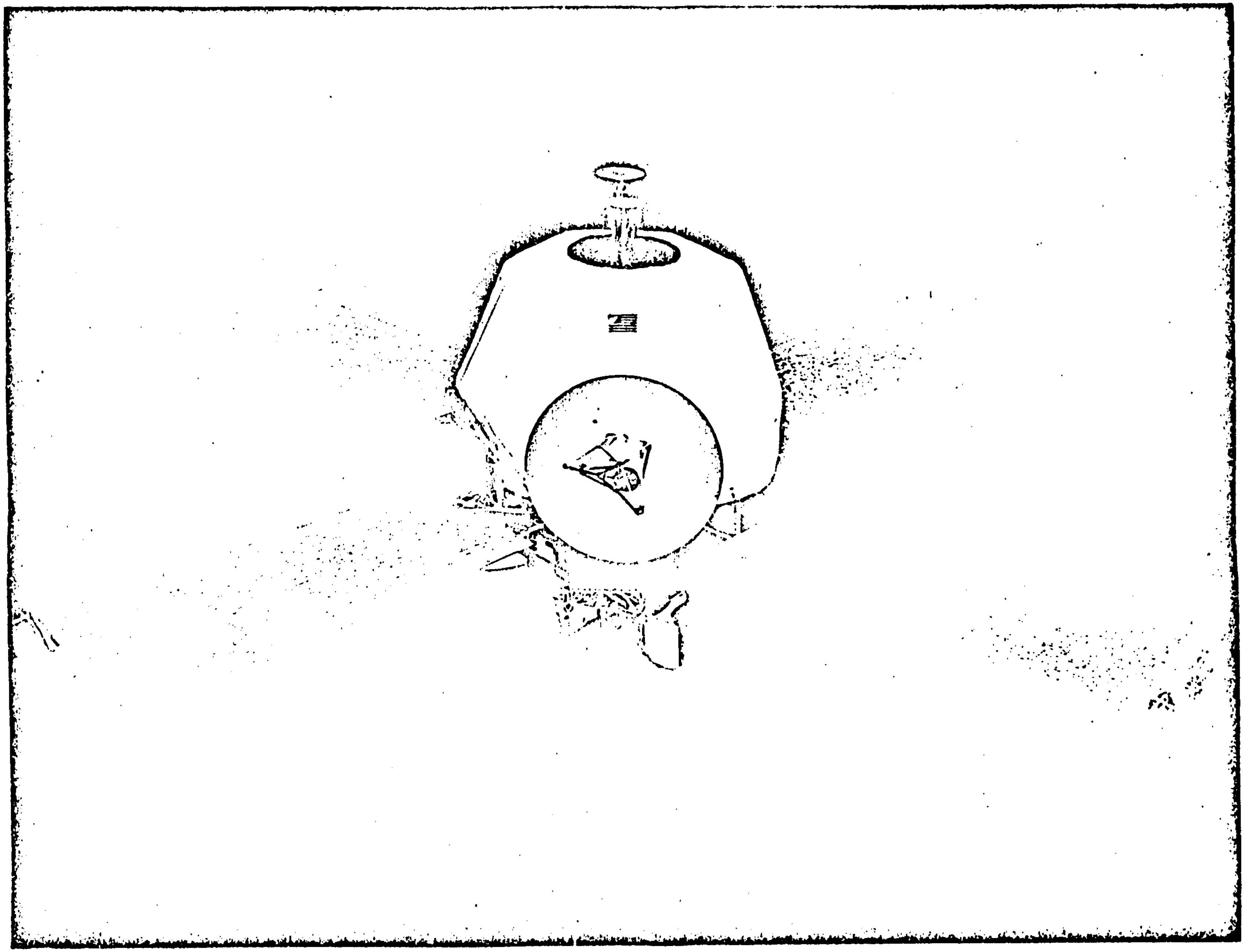


FIGURE IV-7

EFFECT OF LAUNCH YEAR ON MARS-EARTH VELOCITY REQUIREMENT



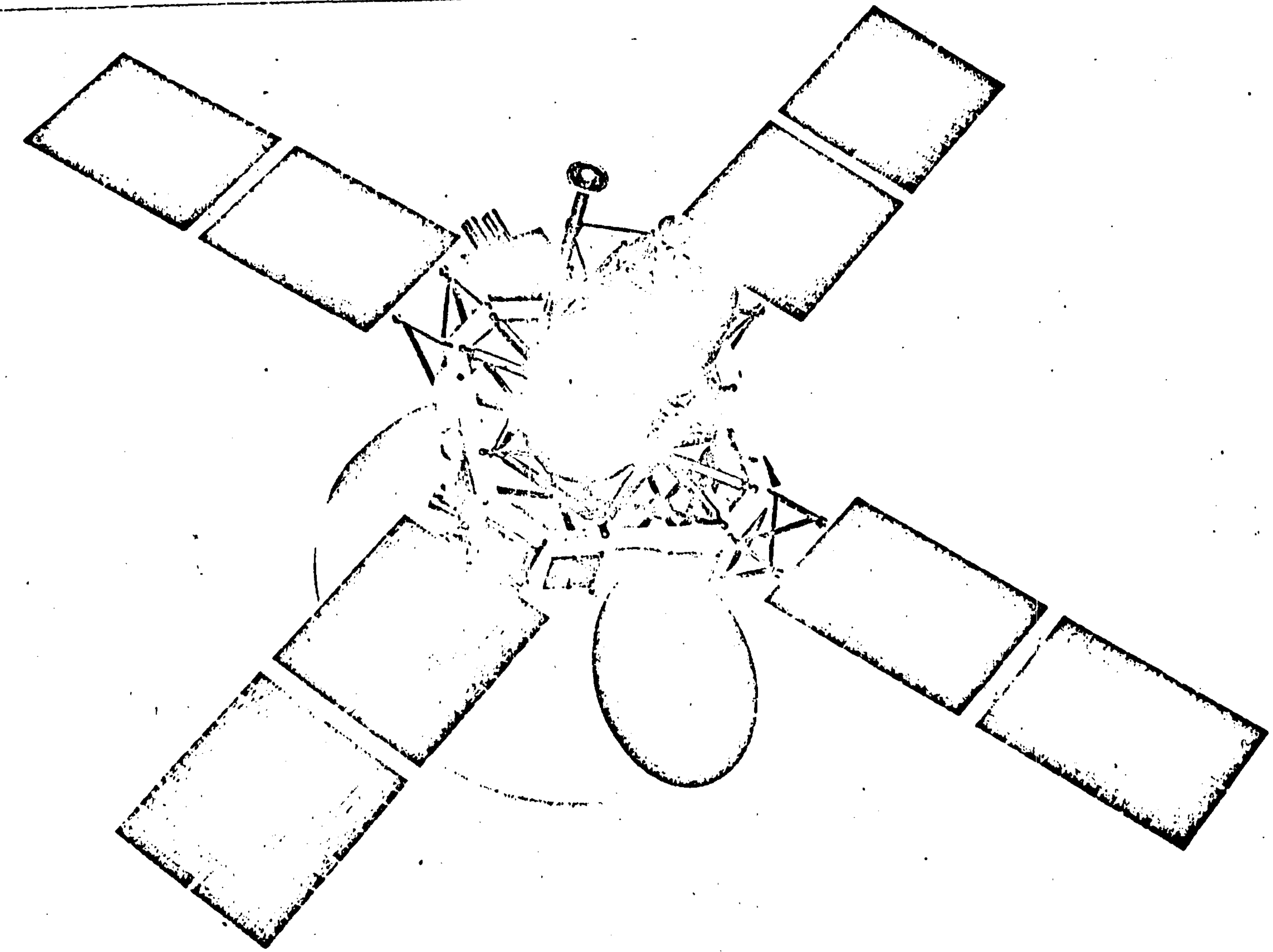
MARINER 9 SPACECRAFT



NASA SL72-2257
12-15-71 (3)

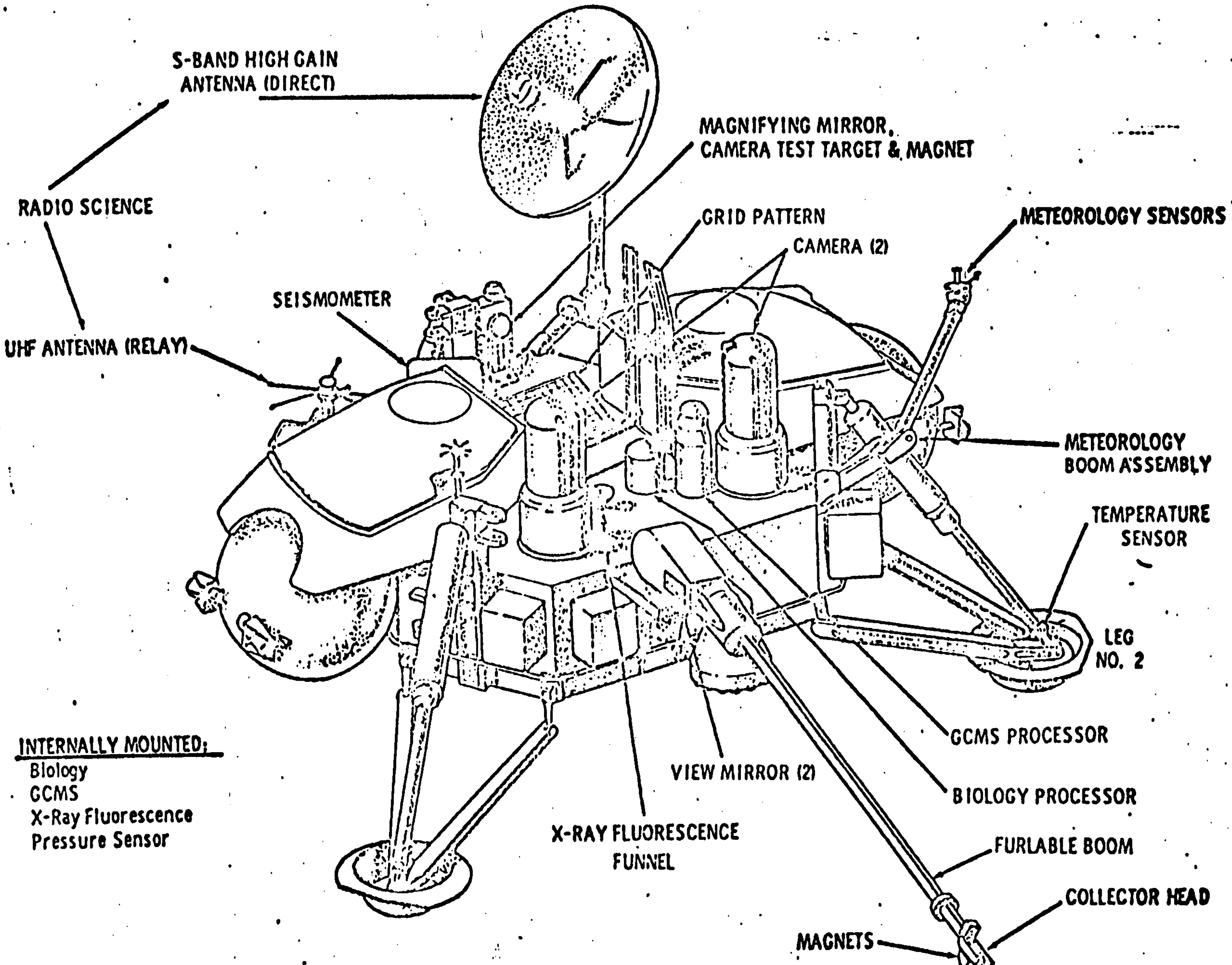
FIGURE IV-9

VIKING SPACECRAFT



NASA SL72-2263 (3)
12-22-71

VIKING ~~LANDER SCIENCE~~ LANDED CONFIGURATION



INTERNALLY MOUNTED:
- Biology
- GCMS
- X-Ray Fluorescence
- Pressure Sensor

FIGURE IV-11, PIONEER VENUS/MARS BUILDING BLOCKS

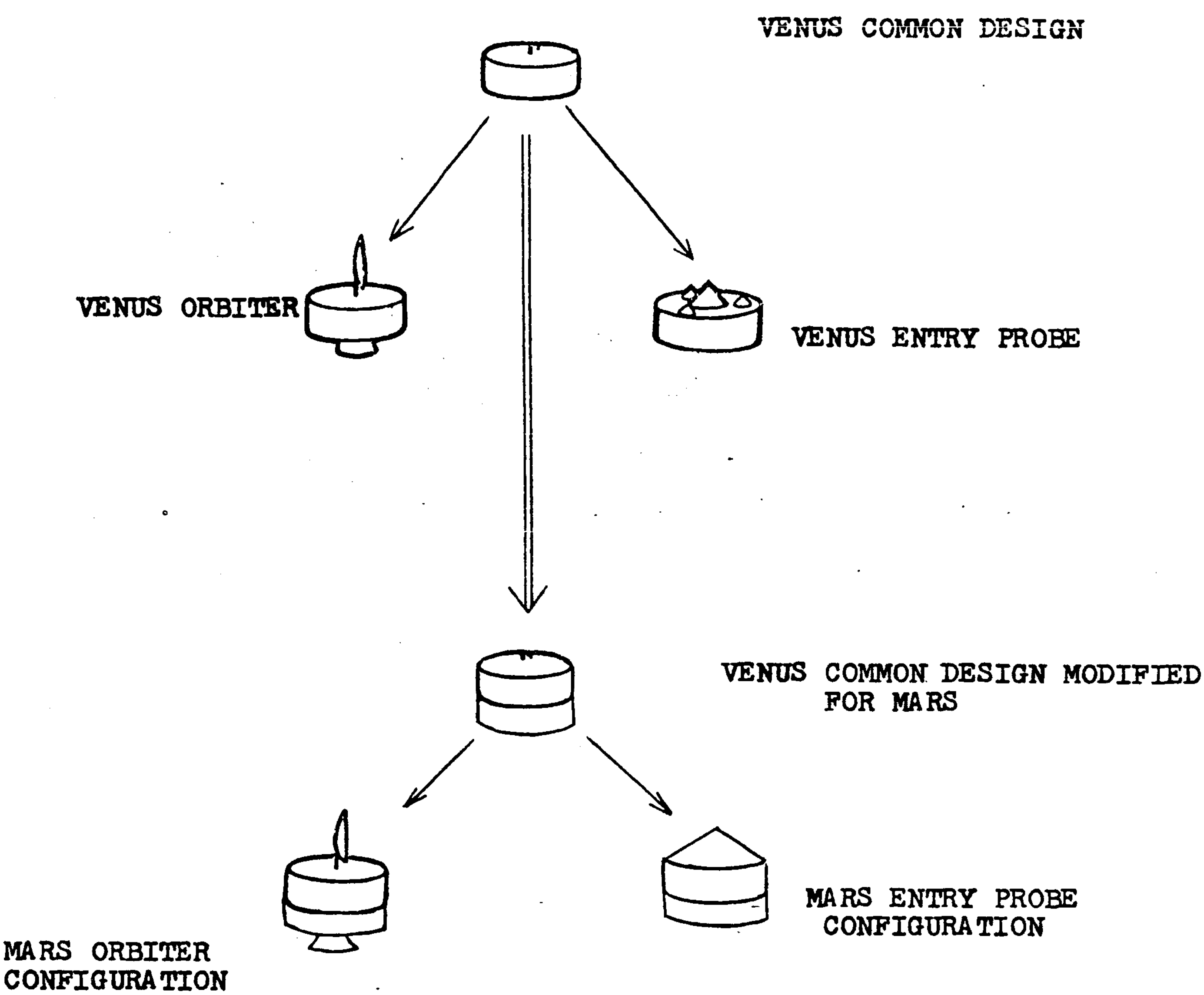
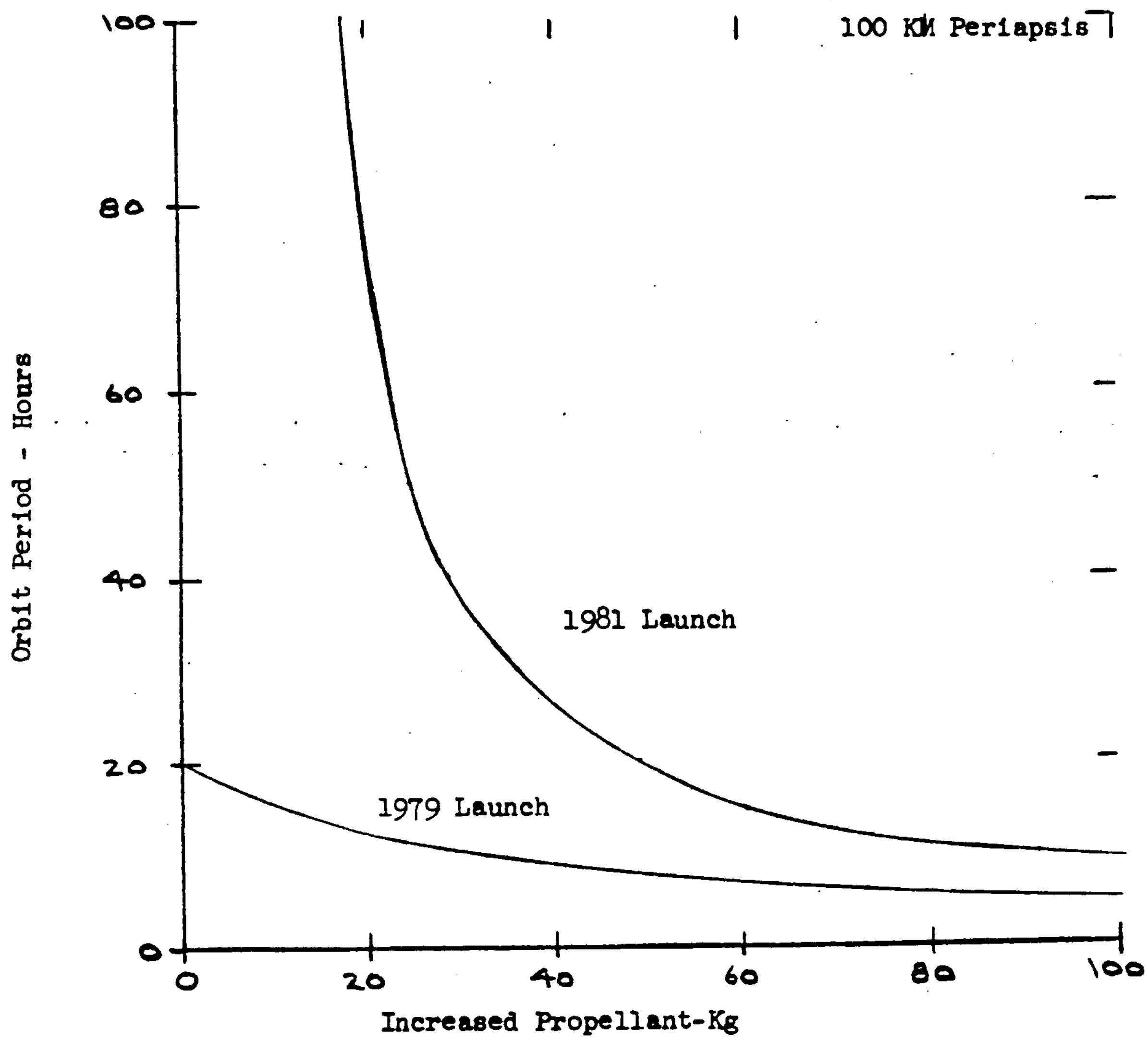


Figure IV-12 . ORBIT PERIOD REDUCTIONS BY INCREASING RETRO PROPELLANT



CHAPTER V

STRATEGY FOR EXPLORATION OF MARS, 1977-81

Development of a strategy for the exploration of Mars in the post-Viking period required the integration into the plan of several influencing factors. For example, although the continuing exploration of Mars is of high scientific interest, the Committee noted that the Space Science Board (Space Science Board, 1971) has recommended that the specifics of any new mission should not be determined until the results of Viking 1975 are available. Further, since proposed strategies of exploration must be fiscally realistic, consideration was given to the fact that missions scheduled for launch after 1981 will have a much higher cost because celestial mechanical constraints will force abandonment of Viking technology. Hence, an advanced Viking class mission offers relatively high cost-effectiveness. Finally, the possibility of obtaining international participation on Mars soft-landing missions was factored into strategy development.

V.1. Summary of Proposed Strategy

a. FY 74

Study the attributes of Mars Surface Sample Return very carefully--define earliest possible launch date, and assess back-contamination problems.

Continue development of potential Viking 79 experiments through SRT funding.

Continue funding further Viking 79 science study (~ $200 K).

Determine the reality of international participation in a Viking 79 rover.

b. FY 75

Decide on Mars Surface Sample Return.

If MSSR can be undertaken in 1981, prepare the request for a new start on this project in FY 76.

If MSSR must be delayed beyond 1981, continue development of instrument options for Viking 79 (~ $5 M), and prepare request for a new start on this project in FY 76 ($15 M).

c. FY 76

Start MSSR (cost unknown now) or Viking 79 ($15 M).

Select Viking 79 science payload (about September, 1976).

V.2. High Priority Missions 1979-81

a. Mars Surface Sample Return (MSSR).

A number of investigations, highly important to an understanding of Mars, can only be practically accomplished by return of a sample to the Earth. These studies include age determination, major and minor element chemical analyses (especially of separated mineral phases), and sophisticated mineralogic and petrographic analyses. The results obtained from small quantities of lunar samples (e.g., Luna 16, 20) can be cited as exemplary of the large scientific returns possible, and, on a purely scientific basis MSSR can be assigned highest priority of all the potential Mars missions.

If, at first glance, these statements sound like conventionally bland truisms, they take on sharpness when the lunar situation is considered. Examination of Apollo samples has resulted in over a thousand major publications—new data presented and new interpretations advanced. The comprehensive analysis and interpretation of Russian Luna samples is even more analogous to the Martian situation. Although our knowledge of planetary evolution will remain incomplete, it will be significantly advanced by receipt of large amounts of geochemical and biologic data from the other Earth-like planets, the type of data dependent on returned sample analysis. Consider some specific examples:

1. Microchemical and mineralogic examinations of individual particles result in thousands of analyses as opposed to a few bulk analyses in remotely controlled experiments. Using paleogeographic techniques, a standard approach in sedimentary petrology and, more recently, in lunar sample analysis, one can reconstruct bedrock composition and distribution over large areas and thereby deduce crustal character and evolution.

2. Presence or absence of mineral species such as clays, carbonates, and nitrates will speak to the issue of water-assisted weathering and surface-atmosphere interaction. Again it is important to draw the distinction between returned sample and remote analysis. The Viking '75 X-ray fluorescence experiment will define a chemistry indicative of clays or barbonates <u>if</u> these minerals comprise the bulk of the samples. But returned sample analysis

will detect these species at the single-grain level. And, from a process point of view, the single grain is as important as the bulk analysis.

3. Integration of analyses from many igneous rock fragments permits speculation regarding bulk crustal composition, presence of one or more differentiation sequences, and differentiation paths within a single sequence.

4. Perhaps the most provocative question regarding the planetary crustal rocks is their age. Radiometric analyses will define crystallization and/or metamorphic ages for some fractions of the total sample, thereby revealing not only the "original" age of the crust but also charting its subsequent thermal history. It is conceivably possible to design a remotely controlled experiment which will make a few radiometric measurements on bulk samples, but this would be more an experimental tour de force than a useful scientific investigation.

If a returned sample mission is designed, we feel that it does not require additional in-flight science to "upgrade" it to some acceptable level. Indeed, the addition of experiments would drive the mission towards undesirable complexity. Perhaps the only instrument necessary is a camera to aid in and to document sample acquisition.

Because of its scientific merit, and because no obvious technological or fiscal barriers have yet come to light, an MSSR mission has been proposed for launch as early as 1981. Here we propose that a very careful study be made of this mission type with the goal of making a decision on launch date during FY 75. Problems requiring study include:

1. The availability of technology necessary for a surface sample return mission.

2. The projected cost of such a mission.

3. The problem of possible back-contamination of the terrestrial biosphere by Martian organisms, including consideration of sterilization procedures and their importance with regard to scientific returns from the mission, and the possibilities of investigations in earth-orbiting laboratories.

The need for resolution of these questions is particularly great because it appears unlikely that both a lander and MSSR would be fiscally feasible in the 1979-81 time period. Indecision on the MSSR could seriously hamper Martian exploration during the 1970's by deferring a Viking '79 decision to a point where it is no longer feasible (loss of Viking '75 team, etc.)

b. Advanced Viking (1979)

A Viking follow-on soft-lander program, while attractive economically and programatically, is justified primarily by the scientific return it can provide. Viking '75, with its focus on biology, carries only a single inorganic geochemical experiment of very limited capability. Thus, in the period 1977-81, planetologically oriented landers or long-lived orbiters (proposed here as a less-expensive mission type) can provide significant new information. Development of new experiments can be carried out in a way allowing significant response to results from the 1976 Viking landings, while retaining the economy inherent in a rapid follow-on.

The sequence of Mars rendezvous opportunities also argues in favor of another mission in the 1970's. A Titan IIIE/Centaur can place a Viking-type spacecraft in Martian orbit from a launch in 1979 or (with modification of the spacecraft to allow additional Δv at Mars) 1981, but not again until at least 1988. Beyond 1981, changes in launch systems are likely, and integration of Viking-type spacecraft with these new systems would be required. Furthermore, a new spacecarft design allowing for much more fuel for Mars orbit insertion would also be required. Economic use of Viking technology can thus only be achieved in launches up to 1981.

It is less expensive to follow-on with a 1979 launch than a 1981 launch because a larger portion of the Viking team will be kept intact. Figures V-1 and V-2 show the manpower profiles for a '75, '79 combination vs. a '75, '81 combination. The latter is seen to represent virtually a new program and cannot fail to be more expensive. This is confirmed by the cost estimates shown in Table V-1 (a portion - about $15 M - of the cost increase is due to the required enlargement of the orbiter propellant tanks for a 1981 launch). Finally, if a mission planned for a 1981 launch cannot meet the schedule, it will be lost due to the unfavorable energy requirements which prevail until 1990.

The 1979 soft-lander mission provides for a large number of variations. There are two basic options: 1) an American Viking-type

TABLE V-1

FOLLOW-ON VIKING 1975 COST ESTIMATE[1]

Repeat Viking 1975; no hardware changes

Single launch, 1979	$200-235 M
Dual launch, 1979	$235-295 M
Single launch, 1981	$260-325 M
Dual launch, 1981	$310-415 M

[1] Estimates provided by Viking Project Office, Langley Research Center, Hampton, VA, May 11, 1973.

soft-lander/orbiter, and 2) an internationally supported Viking-type mission including an autonomous roving vehicle carrying a geoscience experiment package.

Variations on the first option range, in order of increasing desirability, from a carbon-copy Viking '75 repeat, to a Viking with substantially increased geoscience capability, to a Viking with all phases of its science upgraded, possibly including a small, tethered rover for sampling near the lander, and spacecraft modifications required for landings in near-polar volcanic terrain which would be possible with improved targeting after Viking '75.

It would be possible to fly a carbon-copy of Viking '75 in 1979 at relatively low cost, and this could hardly be dismissed as worthless. It does include at least a simple inorganic analysis, and the chance to obtain better coverage of the planet by means of more numerous landing sites is very important. However, while there are these scientific reasons for a duplicate mission, it is unlikely that it would be competitive with other planetary missions in the same time period.

Approximately seventy-five kilograms of additional landed science payload are available on a 1979 lander. The new experiments should include an improved geological experiment package allowing effective study of inorganic chemical compositions, crystal structures, and mineralogy. Candidate experiments include X-ray fluorescence spectrometry, alpha-backscatter spectrometry, gamma ray spectrometry during neutron irradiation, and X-ray diffractometry.

Modifications of a camera to allow "microscopic" investigation of specimens should be included. A further range of improvements in the science package would be possible, with priorities set by the 1976 Viking observations. These changes include:

1. Long-lived (2 earth years, exclusive of lander mission) orbiter and geochemical mapping experiments.

2. Upgraded seismometer.

3. Further orbital geoscience with possible subsatellite for magnetic and gravitational field measurements (inclusion of a surface magnetometer on the lander should be considered).

4. Integrated biology experiment using stable isotopes instead of ^{14}C (adaptable to "life detection," "life characterization," and volatile element (non-metals) geochemistry).

5. Tethered rover (100 m range) for better sample acquisition.

6. Subsurface sampling capability.

7. Smaller lander targeting footprint.

The relative merits of the above options are, at the moment, debatable. While none are mutually exclusive and all might be accommodated on the same spacecraft, their total cost could be too high. A much better-informed choice among these options can be made in September, 1976, when the major features of the Viking 1975 results should be apparent. In the interim, expenditure of about $20 M on instrument development will be required in order to allow an effective response to the 1976 results in time to permit a more economical 1979 launch.

The approximate costs (dual launch assumed) of various science options are shown in Table V-2. The minimum dual mission, exclusive of launch vehicle and mission operations, would cost about \$320 M, with a ceiling of about \$410 M, taking into account logical improvements. These costs would be spread over the fiscal years 1975-1981, with a start of about \$5 M being required in FY 1975.

Studies indicate that there are two interesting rover classes. The first, noted above, is a tethered rover with limited range and few, if any, functions other than sample collection. Such rovers are estimated to cost about \$10-15 M and can be an American advanced rover, independent of European support. The second class includes non-tethered rovers with independent power supplies and onboard science. Communications and control costs are great enough to make these rovers attractive only when a substantial range ($\geq$ 25 km) and rather elaborate onboard science are considered, and the cost is probably around \$100 M.

The possibility of a long-range rover depends largely on the reality of international support. By traversing geologic boundaries, the rover effectively accomplishes additional "landings" and might provide the best possible evidence of geochemical differentiation. It can also reach sites of high scientific interest which are not directly accessible to a lander. The international mission can be favored both because of the increased scientific return and as a start on invaluable cooperation. Rapid progress will depend on the

TABLE V-2

ESTIMATED COSTS FOR FOLLOW-ON VIKING MISSION OPTIONS[1]

Science Option	Estimated Cost
Integrated geology	\$18-25 M
Two Earth year orbiter lifetime	\$16 M
Gamma ray spectrometer	
Upgraded seismometer	
Subsatellite for magnetic and gravitational field measurements	\$15-20 M[2]
Integrated biology experiment	\$25-30 M
Tethered rover (10 m range)	\$10-15 M
One meter drill	\$ 9 M
Improved polar landing latitude	\$17 M

[1] Estimates provided by Viking Project Office, Langley Research Center, Hampton, VA, Nov. 30, 1972.

[2] Reported cost of same option for MOSS. No Viking estimate available.

effective transfer of technology to European partners. The mission has the potential of being slow and expensive in development, the expense possibly resulting from delays as well as costs of rover integration. Nonetheless, the benefits could out-weigh the risks. This option will require careful study of specific plans before any firm conclusions are justified.

It is our view that biology should not be entirely dropped from an upgraded Viking for a number of reasons. First, any increase in knowledge about Martian biology helps to clarify questions about sample return mission. Second, the Viking '75 biological results are certain not to tell the whole story, and the necessity of further study is inevitable.

V.3. Long-Lived Orbiter Missions

If funding will not allow a soft-lander/orbiter mission in 1979, the long-lived orbiter alone forms an attractive alternative that can answer questions not resolved by Mariner 9:

1. Long term (seasonal) variations in the atmospheric composition and circulation.

2. Seasonal changes in visible features of the planetary surface.

3. Chemical composition of the planetary surface as determinable by remote sensing.

4. The detailed mass distribution and magnetic properties of the planet.

By studying atmospheric composition and circulation together with surface features and composition, an orbiter with a lifetime of two Martian years (four Earth years) can provide information on dynamic interactions between the atmosphere and the surface (one Martian year would normally suffice, but competition for tracking facilities does not allow uninterrupted coverage). The distribution of K, U, Th, Fe, Mg, and O (and possibly of Ca, Al, and Ti) can provide substantial information on the geochemical complexity and evolutionary state of the solid planet. Near infrared mapping of the surface can provide data on the distribution of hydrated minerals. High resolution photography of surface features will allow more extensive inference about Martian structural geology and geological history. A radar altimeter is useful in the same context.

A magnetically clean subsatellite can study the magnetic field, and orbital tracking of this subsatellite should allow determination of the gravitational field, both providing very significant information on the overall mass distribution and internal structure of the planet. Some or all of the geochemical mapping experiments might be flown on the subsatellite, thus increasing their resolution in terms of surface regions.

A possible form of long-lived orbiter based on Mariner 9 and MJS technology has been studied by JPL and given the name "MOSS," for Mars orbiting science station. Other spacecraft types may be applicable, but are insufficiently studied at the moment. Total cost of a 1977 MOSS launch, exclusive of launch vehicle, is estimated at $131 M spread over fiscal years 1974-82, with a maximum of $35.5 M in FY '77. Because of slightly less favorable transfer of technology and sharing of mission operations, 1979 and 1981-launched missions have costs of $5-10 M greater.

REFERENCES TO CHAPTER V

Space Science Board, National Research Council, 1971, "Priorities for Space Research 1971-1980," National Academy of Science, Washington, D.C., p. 27.

Figure V-1
MANPOWER[1]

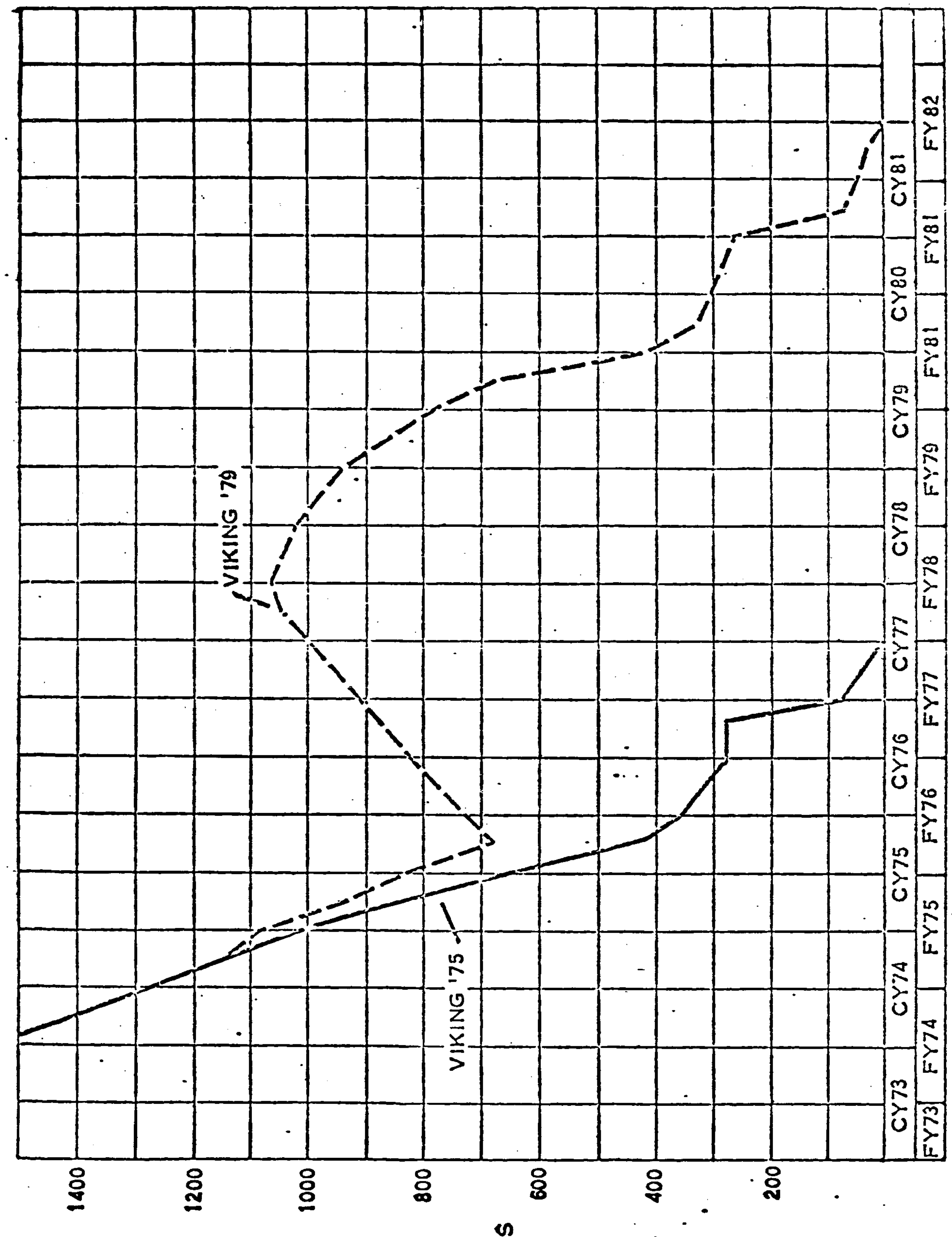
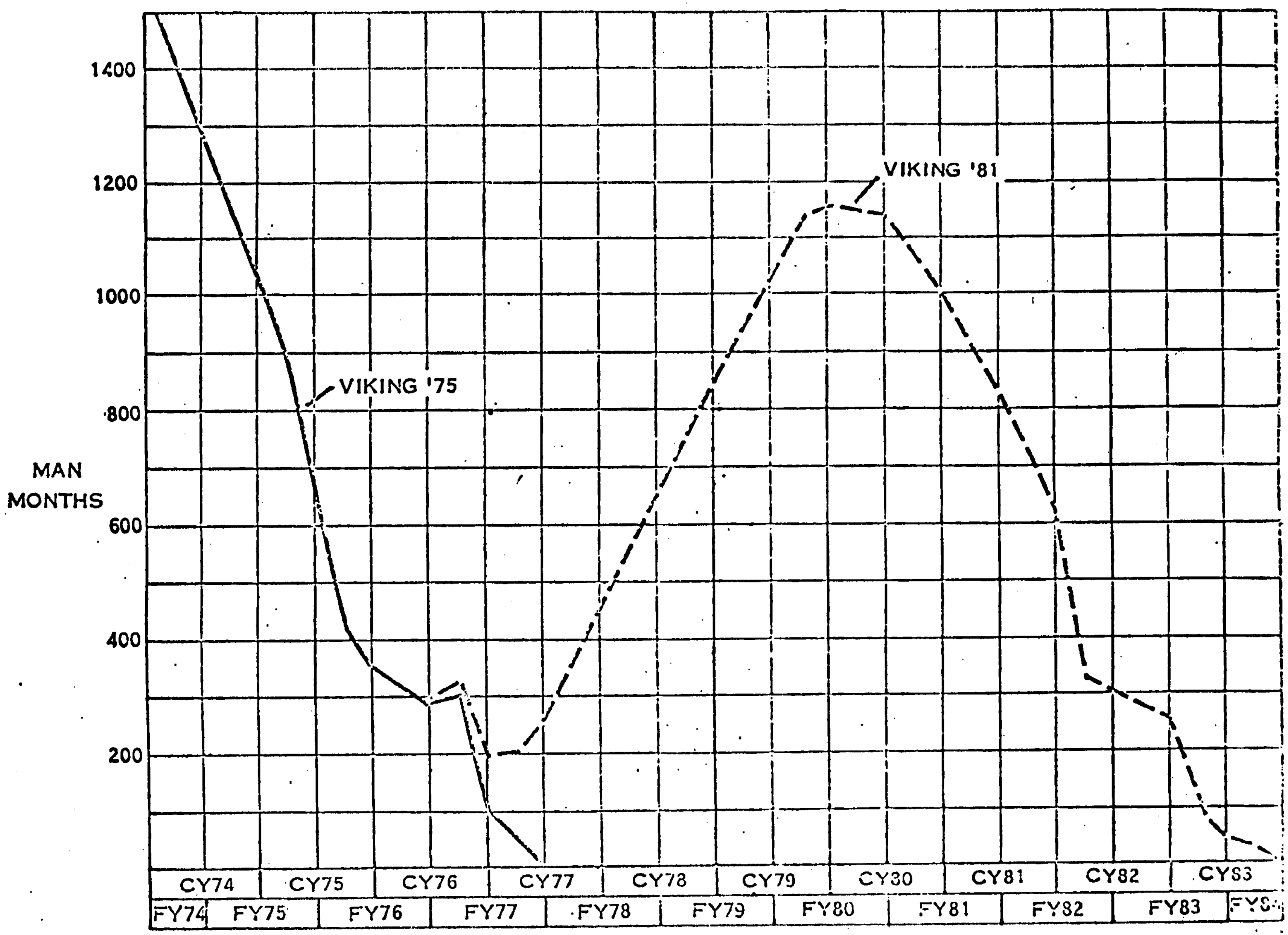


FIGURE V-2
MANPOWER'



CHAPTER VI

STRATEGY FOR EXPLORATION OF MARS BEYOND 1981

If a Mars surface sample return mission is not carried out in the 1979-81 time period, then it becomes a prime candidate for the post-1981 exploration phase. Another possible mission would be to land an autonomous roving vehicle which would have a range of 1000 km, for example, and which would carry an array of scientific investigations on-board. A third possibility could be to pursue a Phobos or Deimos lander mission. Studies have shown that such missions are technologically feasible and, in addition, would provide a long-lived Mars observation post. This mission is of scientific interest because comparing the composition of Phobos and Deimos with the composition of Mars may prove to be as rewarding as comparison of the compositions of the Moon and the Earth has been.

A fourth strategy for exploration of Mars beyond 1981 involves a series of Pioneer-class orbiters and/or landers performing a limited number of investigations on each mission, but covering a wider range of planetary regions. The increased energy requirements for Mars trajectories during the mid to late 80's make the Pioneer spacecraft more attractive than Mariner. Furthermore, our knowledge of Mars by this time may be such that dedicated missions to answer specific questions may be an appropriate approach to follow. For these and other reasons noted below, candidate Pioneer-class missions were investigated in some detail and are described in the following sections.

VI.1. Pioneer-Class Missions

Pioneer-class missions are attractive primarily because they are low-cost. Their liability is that they are scientifically limited. In general, candidate experiments must be low in weight and volume, and must use little power. The returned information has to be acquired over a short period of time and transmitted over a data link of modest capacity. Experiments have to survive adverse environments (e.g., high-g conditions for hard landers).

The liabilities indicated above do not preclude scientifically productive missions, but they require the formulation of focused scientific questions that can be answered with selected and limited data. If the presumed model is incorrect, then the experimental results may be inapplicable and therefore essentially useless. Similarly, if the experimental results are incomplete, of poor quality, inferential, or otherwise ambiguous, then they will not be adequate to confirm or eliminate the proposed model. To that extent, we will be unsuccessful in increasing our fundamental knowledge concerning planetary character, origin, and evolution.

To a remarkable degree Pioneer missions stand in contrast to Viking-type soft-landing missions in which a general-purpose experimental package is employed to perform a reconnaissence of the planetary surface. One cannot deny the intellectual elegance of the Pioneer approach--defining a fundamental thesis and then collecting only the data critical to the testing of that thesis. Although the Viking reconnaissance philosophy might seem comparatively crude we argue that it is, in fact, the appropriate approach considering the present state of our knowledge. It follows that, at some time in the future, there can be a cross-over--a point at which specific questions can be formulated and best answered with small, directed spacecraft.

VI.2. Pioneer-Class Mission Capabilities

The following Pioneer missions are candidates: (1) small spin-stabilized orbiters; (2) orbiters with subsatellites; (3) small atmospheric probes; (4) small hard-landing probes; (5) surface penetration probes; and (6) small soft landers. These missions are further described in Chapter IV and Appendix I. Salient information is summarized in Table VI-1 which lists: (1) available space for experiments; (2) available weight for experiments; (3) available power for experiments; (4) maximum lifetime; (5) bit rates and total transmission capability; and (6) targeting constraints.

It should be emphasized that these figures are, in almost all cases, uncertain. We have made a concerted effort to review previous Pioneer missions and to become familiar with planned Mars applications. In almost every case, the demonstrated capability of a Pioneer-type mission appears inadequate or marginally adequate for the accomplishment of the scientific goals we specify. Although we anticipate that close study will result in improvements of those values given in Table VI-1, the history of space exploration indicates that such

TABLE VI-1

Mission / Parameter	Available Experiment Volume, m^3	Available Experiment Weight, kg	Available Experiment Power, Max watts	Maximum Lifetime,	Bit Rate and Total Trans. Capability	Targetting Constraints
(1) Small spin stabilized orbiter	~ 0.1	40	30	probably greater than 2 years	100 to 2000 BPS	Target at 800 km periapsis
(2) Small orbiter with satellite orbiters	≈ 0.05	10	15	90 to 360 days	20000 BPS (to orbiter)	can reach 120 km circular
(3) Small orbiter with satellite entry probes	≈ 0.02	8	10	< 1 hr	≈ 1000 BPS (to orbiter)	±2° at entry
(4) Single entry probes (no orbiter)	≈ 0.02	8	10	< 1 hr	≈ 1000 BPS to fly-by bus	±2° at entry
(5) Multiple entry probes, per probe	≈ 0.02	8	10	< 1 hr	≈ 1000 BPS (to fly-by bus	±2° at entry
(6) Small softlander	≈ 0.1	30	10, ave	90 days	2000 BPS (to orbiter)	±1° at entry
(7) Softlander with satellite penetrometers	≈ 50×10^{-6}	1	<<1 watt	90 days Max (2 to 3 nominal)	28000 BPS at impact; 14 BPS normal	
(8) Single penetrometer	≈ 0.01	≈ 10	≈ 1 watt	2 to 90 days	3000 BPS (to orbiter) or 1 BPS to earth	±2° at entry
(9) Multiple penetrometers	≈ 0.01	≈ 10	≈ 1 watt	2 to 90 days	3000 BPS (to orbiter) or 1 BPS to earth	±2° at entry

Notes: Data given in row (2) are for the subsatallite only, add to (1) for the total system
Data given in row (3) are for the entry probe only, " " " " " " "
Data " " " (4) presume relay transmission via a fly-by bus.
Data " " " (5) are the same as row (4) because these probes are small (total weight - 24 kg)
Data given in row (7) are for the satellite penetrometer only, add to (6) for the total system
Data given in rows (8) and (9) are the same because they are small, ≈ 150 kg and several could be carried by a pioneer class spacecraft.

All data is based on Use of the Pioneer as orbiter or bus. No launch constraints are given because the shuttle and various tugs and upper stages will be available in the 80's which are not well defined at this time.

optimism is not always justified. Under adverse conditions, a Pioneer mission could grow in complexity and expense to a point where it rivalled larger spacecraft without incorporating the advantages inherently a part of these larger buses.

VI.3. Scientific Payloads for Pioneer-Class Landers

We list some fundamental questions that might be answered with Pioneer-type experiments. For each of these situations we indicate some fundamental constraints:

a. Chemical/mineralogical variations across Martian surface.

With Mariner 9 data in hand one can identify at least five terrains of broad extent--cratered terrain, cratered plains, smooth plains, mantled terrain, and laminated polar plains. These surfaces are shaped by different geomorphological processes and are perhaps underlain by rocks/sediments of differing composition and age. Characterization of these differences would elucidate differentiation of the crust both by internal processes and by surface-atmosphere interactions.

Because of the regional character of these terrains, targeting is not critical. X-ray fluorescence and alpha experiments could be contained in either soft landers or penetrometers. Hardening of an X-ray diffractometer might prove difficult. In the case of the penetrometer, visual characterization would be precluded. Meaningful interpretation of a single sample (or, at best, repeated samples from the same spot) might prove difficult.

b. Heat flow.

This is an important parameter for understanding thermal/ igneous evolution of the planet. The experiment may be appropriate for a penetrometer.

Targeting is not a serious problem. Penetration to 1-2 meters should be adequate to eliminate diurnal variations. Attainment of equilibrium before taking measurements might require several days.

c. Soil moisture.

The Martian water cycle is clearly important, and presently poorly understood. The experiment could be contained in a penetrometer. Attainment of equilibrium conditions may prove difficult. In order to exploit the investigation, measurements should be made at different soil levels (possible), over several diurnal cycles (possible), and over several seasons (unlikely).

d. Subsurface structure.

Critical questions regarding the evolution of Mars relate to the possible presence and thickness of a regolith, crustal-scale layering beneath the soil zone, and possible presence of a permafrost zone. These questions might be addressed with geophysical experiments, notably, seismometers and electromagnetic sounders.

Severe constraints exist. The seismic experiment would have to be active. The seismometer could be contained in a penetrometer or a soft lander and the explosive charge on an auxiliary penetrometer. Lack of prior information regarding the geologic setting would be disabling. At present we have no model of surficial layering against which the seismic data could be judged. Even if this model existed, site-specific variations might prove overwhelming.

Electromagnetic sounding is a technique recently developed for terrestrial application and used on Apollo 17. Deployment of the single wire presumably designed for both sending and receiving would be difficult. Lunar experience indicates that interpretation of results is not definitive, even in the presence of a great deal of supporting information.

e. Polar phenomena.

Current climatological models depend on assumptions regarding CO_2 and H_2O storage in polar caps and the long-range cycling of those materials. It would be highly desirable to have better and more direct information regarding the distribution of H_2O and CO_2 in the cap. A penetrometer with a H_2O sensing device would be useful in that regard.

By itself, a penetrometer measurement might be of little use. The mere detection of water ice, or even the volume determination of that ice at one site and at one soil horizon, does not answer the mass balance question posed in the preceding paragraph. To answer that question, long-term orbital pictures and radiometric measurements are most useful. In fact, they may be independently adequate.

VI.4. Pioneer-Class Orbiter - Upper Atmosphere

The question of the origin and evolution of the Martian atmosphere can be investigated with a Pioneer-class orbiter. Such a spacecraft in a low periapsis orbit (1 μb level) will be able to measure the composition of the neutral and ionized constituents of the upper atmosphere of Mars. The objective of such a mission will be to measure short-term and long-term variations in the composition and structure of the upper atmosphere.

Mariner spectroscopic instruments and earth-based observations have established that the atmosphere of Mars is predominately carbon dioxide, the amount of atomic oxygen, molecular oxygen, and carbon monoxide is small, water vapor and ozone are present in the lower atmosphere, and atomic hydrogen is escaping from the top of the atmosphere. Large variations occur in the amount of water vapor and ozone in the lower atmosphere, but the amount of atomic oxygen and atomic hydrogen in the upper atmosphere appears to be relatively constant. Theoretical models indicate that changes in the composition of the lower atmosphere should result in changes in the composition of the upper atmosphere. Yet, <u>over the limited observational period</u> of the Mariners, the densities of atomic oxygen and atomic hydrogen remained essentially unchanged. (Mariner 6 and 7 made single observations 5 days apart. A little more than two years later in 1971-72, Mariner 9 made extensive observations for 170 days, but this time period was less than a single Mars season.).

Theoretical ideas relate the dissociation of water vapor with escape rate of atomic hydrogen and atomic oxygen and further suggest that the escape rate of these atoms is self-regulating. The measurement of the escape flux of these two constituents over a time period of one or more Martian years (23 earth months) will test whether or not changes occur. The search for diurnal, seasonal, or secular changes will lead to an understanding of whether or not the Mars atmosphere is presently evolving, and how it may have evolved in the past.

Certain minor constituents in the upper atmosphere (concentration less than 1%) react with the ionized constituents and produce a change in the composition of the ionosphere. For example, even very small concentrations of nitric oxide are easily ionized producing nitric oxide ions and diminishing the density of the other ions. The measurement of the ion density is a sensitive method of determining the presence and density of minor constituents. Theoretical models suggest that the composition of the ionosphere is intimately connected to the escape of atomic nitrogen as well as atomic oxygen. Subtle changes in the composition may enhance or subdue the escape rate of the minor constituents. A long-lived orbiter will be able to determine if there are seasonal or secular changes in the composition of the upper atmosphere and how the ionosphere responds to these changes. This information may be used to determine the present escape rate of the constituents and what their abundances must have been in the past.

A Pioneer-class orbiter for upper atmosphere studies should be instrumented in a way similar to the Atmospheric Explorer - C,D,E earth satellites. On this mission, there is a complement of mass, ion, and optical spectrometers, density guages, and electron temperature analyzers. The Pioneer-class spacecraft would need to have an on-board rocket motor to lower and raise periapsis for use in the same operational manner as will be done with Atmospheric Explorer.

Entry probes are not recommended for additional Mars atmospheric studies. An excellent set of experiments will be conducted on Viking 1975 to measure the vertical structure. The key remaining questions concern changes in the composition and structure of the atmosphere. Investigating seasonal changes with atmospheric probes would take a large number of individual probes evenly spaced throughout the Martian year. Such an approach would be prohibitive in both its operational and resource requirements, while an orbiter makes this type of observation quite adequately.

VI.5. Pioneer-Class Orbiter - Lower Atmosphere

The characteristics of the lower atmosphere which can be measured or inferred from a satellite are: temperature, surface pressure, winds, composition (including the variable constituents: water vapor, ozone, dust, ice particles), and cloudiness. Since we are interested in dynamics, it is the time and space variations of these quantities which need to be measured; and it is for this reason that orbiters are the only practical means for measuring dynamical processes in the lower atmosphere.

The Nimbus and NOAA satellites and the Mariner 9 orbiter have amply demonstrated the capability of orbiters to measure temperature variations using the 15 micron bands of CO_2 together with radiance in a transparent "window" region of the spectrum. Both

Nimbus and Mariner 9 have used the IRIS spectrometer. Alternative instruments, which can also obtain roughly equivalent information, would be spectral channel instruments like the SIRS, now flown on NOAA satellites, or the Selective Chopper Radiometer (SCR) flown on Nimbus satellites. Alternatively the Limb Scanning Radiometer now scheduled for Nimbus G could be used. This device would have the advantage of providing improved vertical resolution compared to the other instruments, and would also provide data to higher levels (up to 80 km or so). The latter three instruments record data in specific channels and could thus function at a much lower data rate than the IRIS. This could be a distinct advantage for a long-lived mission at relatively low cost.

Surface pressure can also be obtained from thermal infrared spectra as well as by radio occultation. Accuracies of the thermal infrared technique using IRIS are about 10-20%, while the accuracy of the occultation measurement is a little better. Accuracies needed to infer synoptic and diurnal meteorological variations are about 1%, latitude variations about 2%, and seasonal variations in mass about 3%. The most promising possibility appears to be measurement in a near infrared band of CO_2 utilizing reflected solar radiation. Using a weak band it should be possible to obtain sufficient accuracy to sort out seasonal variations in mass with a relatively simple device.

Wind distributions can be inferred from the three-dimensional distribution of pressure variations. The latter can be obtained from the temperature and surface pressure fields if the spatial variations in pressure on a constant geopotential surface have been resolved. Even if the resolution of pressure measurements is not adequate for this purpose, wind distributions can be inferred with acceptable confidence using models incorporating temperature data alone, provided that there is sufficient time and space coverage. This is true, in principle, on any planet; but it is a relatively straightforward problem on Mars because of the similarity of the important coriolis force to that of the earth.

Ozone variations can be inferred from measurements in the near ultra-violet; they can also probably be inferred from limb-measurements in the 9.6μ infrared band. If the latter measurement proves feasible, vertical ozone structure could probably also be obtained using this type of information. Water vapor concentration can also be measured in the thermal infrared using IRIS, or in the near infra-red, using MAWD. It can also be measured by using the additional channels of the Limb Scanning Radiometer mentioned previously. The spectral signature of ice clouds was clearly identified by the Mariner IRIS, and could probably be detected also by using additional dedicated channels in the thermal IR or near IR. Airborne dust can be identified by near IR spectral measurements.

APPENDIX I

CHARACTERISTICS OF MARS MISSION OPTIONS

A I.1. Pioneer Long Life Orbiter

a. Objectives

Use an inexpensive long-life spacecraft in orbit around Mars to observe the atmosphere and surface by remote sensing.

b. Mission Description

A single spacecraft will be launched by an Atlas/Centaur launch vehicle during the 1979 or 1981 launch period. It will fly to Mars on a type II trajectory and perform two or three midcourse trajectory corrections enroute. At closest approach to Mars, the spacecraft will be inserted into orbit by a solid propellant retro-rocket. The initial periapsis altitude will be about 1000 km to conform to planetary quarantine requirements. The orbit period will be 12 to 24 hours. During each orbit, most of the data will be collected near periapsis, stored, and transmitted to earth later in the orbit. The nominal spacecraft life will be one Martian year.

c. Science Payload

The science payload may be based on the instruments flown in the Pioneer Venus orbiter, or will incorporate some of the instruments discussed in Section VI. Table AI-1 is a model payload for the Pioneer Venus orbiter mission. Other instruments which might be included in a Mars orbiter payload include a spin-scan TV camera and near infrared and thermal infrared spectrometers.

Table AI-1

Experiment	Instrument	Weight (kg)	Power (w)	Data (bps) (nominal)
Solar wind/ionosphere interaction	Magnetometer[1]	3.5	2	32
	Solar wind and photo-electron analyzer	2.5	2	36
	Electron and ion temperature probe	2.0	3	25
Aeronomy (composition, photochemistry, airglow)	Neutral mass spectrometer	4.0	10	100
	Ion mass spectrometer	1.5	1	100
	UV spectrometer/ photometer	6.0	4	$\leq$600
Atmosphere (thermal structure, lower atmosphere density)	IR radiometer	5.0	4[4]	150
	Dual frequency occultation (add. X-band)[2]	3.0	10	-
Surface (topography, reflectivity, roughness)	Radar altimeter[3]	9.0	11	300
		36.5	~30[5] (Avail.)	128[5] (At max. distance)

[1] Including 2- to 3-m boom.

[2] Associated with the telecommunication subsystem (S-band).

[3] A dedicated antenna is preferred to one shared with the communications system.

[4] Must be 14 w if a horizon scanner is used.

[5] To satisfy payload requirements on power and data rates, a proper duty cycle will be necessary.

d. Spacecraft Characteristics

The Pioneer-long life orbiter will be derived from the Pioneer Venus orbiter. It will be spin stabilized and use solar cells to provide power. It will cruise and orbit with the spin axis perpendicular to the ecliptic plane. The science instruments will weigh about 40 kg and use about 30 watts of power. Science data may be transmitted to Earth in real time or stored for later transmission to Earth at a lower bit rate. Data from several instruments may be combined by selecting one of several data formats. Data acquisition may be controlled by real time commands or by activation of stored command sequences. Data transmission to Earth will use an S-band radio link which includes a de-spun high gain antenna. Data rates will be 100-2000 bits per second.

e. Spacecraft Configuration

The spacecraft body will be a cylinder with the solid propellant retro motor mounted on the bottom and the high gain communications antenna mounted on the top. It will have solar cells attached to the outside. Science instruments will be mounted on an open shelf to provide views along the spin axis, normal to the spin axis, along the velocity vector, or normal to the velocity vector. Instruments may be mounted on gimbals to allow moving their fields of view.

A I.2. Mars Orbiting Scientific Station (MOSS) Mission

a. Objectives

The objectives of this mission are to gather new science information using a long-life orbiter that emphasizes temporal observations and measurements of the atmosphere/surface interactions, the evolutionary nature of the planet, details of specific surface features and an expansion of the geosciences.

b. Mission Description

The mission would be launched in the late 1970's or early 1980's time period; 1977, 1979, 1981 or 1983/84 opportunities. The orbiter would be designed for operation in a near-polar, elliptical orbit for 2 Martian years. The 12-hour period, 700 km periapsis-attitude orbit will migrate over the full range of latitudes during the lifetime, allowing high-resolution coverage of any spot on the planet. An observatory approach to science is considered in that a small number of Investigators would be selected and dedicated to the entire project and many visiting experimenters would take part in the mission on a limited time basis. An attractive addition to the mission is the inclusion of a small Apollo-type subsatellite for low altitude particles and fields mapping.

c. Science Payload

The payload on the MOSS would consist of television cameras capable of both synoptic and high-resolution coverage, geophysical and geochemical instruments, and spectrometers capable of measuring atmospheric temperature profiles, atmospheric water vapor and ozone distribution and surface temperatures. The subsatellite payload might consist of a γ-ray spectrometer, magnetometer, doppler gravity and radar altimeter.

d. Spacecraft Characteristics

The MOSS spacecraft makes extensive use of technology development for the Viking and Mariner programs to enhance system capability and reliability and to minimize cost. The spacecraft mass is 1100 kg. The MOSS propulsion subsystem will provide a velocity change capability of about 1525 m/sec for this separated mass. Other features of the MOSS spacecraft include a two-degree-of-freedom, steerable high-gain antenna, an X-band transmitter that permits transmission of real-time television pictures from Mars, and a scan platform with increased viewing envelope to provide greater selectivity of science targets throughout the mission.

The subsatellite is spin stabilized, has direct-to-Earth communications, is solar powered and has a small propulsion system for orbital changes. It weighs about 50 kg.

e. Spacecraft Configuration

The MOSS configuration is shown in a pre-launch mode in Fig. A I-1.

A I.3. Viking Long Life Orbiter

a. Objectives

The objective of the mission is to gather new science information using a long life orbiter that emphasizes temporal observations and measurements of the atmosphere/surface interactions, the evolutionary nature of the planet and details of specific surface features.

b. Mission Description

The mission would be an integral part of the Viking 79 mission. This mission provides the capability of adding sufficient attitude control fuel to the Viking orbiter to survive for one Martian year in a near polar, eliptical orbit with a period of 24 hours. During this time the periapse will migrate over a latitude range of 90 degrees, allowing high-resolution coverage of one hemisphere. The observatory approach taken in the MOSS mission discussed previously could also be employed here.

c. Science Payload

The science payload would be the same as Viking 75 with the possible addition of one instrument in the geoscience area.

d. Spacecraft Characteristics

The spacecraft is the same as the Viking 75 orbiter and may make use of spare 75 hardware.

e. Spacecraft Configuration

The spacecraft is the same as the Viking 75 orbiter.

A I.4. Pioneer Mars Survivable Hard Lander Mission (CSAD)

a. Objectives

The objective is to obtain data on Martian particles and fields, atmospheric properties and surface composition.

b. Mission Description

This mission would be flown during mid-1980's and its science would be tailored to conduct specialized investigations at particular locations on Mars. The mission concept involves inserting the orbiter/lander into Mars orbit, and separating the lander which descends to the surface via a parachute and survives the surface impact.

c. Science Payload

Science on-board the orbiter would consist of particles and fields experiments; and the lander would be equipped with temperature, pressure and composition instrumentation for measurements during descent. On the surface the lander would be equipped for surface composition, meteorological and seismological measurements. Payload on the orbiter is not mass-constrained and the lander payload mass is approximately 30 kg.

d. Spacecraft Characteristics

Design of the bus/orbiter is based on the Pioneer Venus spacecraft, and the survivable hard-lander is derived from the CSAD. The lander is enshrouded in impact material and is designed to operate on the surface for several days. It is battery powered and telemeters data to the orbiting spacecraft via a relay link. Total injected mass of the spacecraft and probe is approximately 490 kg, which includes 190 kg for the hard lander and a ΔV capability of 1500 mps on-board the orbiter. This ΔV is sufficient to achieve a 24 hr orbit for most opportunities. The stable of launch vehicles available are adequate for all Mars opportunities.

e. Spacecraft Configuration

The CSAD lander is shown in Fig. A I-2.

A I.5. Penetrometer Probes

a. Objectives

The objective of this mission class is to provide relatively specialized information over a brief period of time in the geological and atmospheric sciences.

b. Mission Description

Such missions would probably not be undertaken until the period of the 1980's, and would be used to gather data in answer to specific questions at a number of points on the Martian surface. Several probes would be transported to Mars by a Pioneer class orbiter or bus. There are several mission options: a) They could be deployed for entry either in the direct or out-of-orbit entry modes, decellerate aerodynamically to impact velocities of several hundred meters/sec, impact and penetrate three to five meters with the subsoil probe (leaving the communications and surface instrument package on the surface), b) They could be carried on a large hard lander and deployed from an altitude of about 2000 meters, reducing the impact velocity, all other operations being the same as (a). Because of battery lifetime problems these missions would be limited to a lifetime of two or three days. The development of hardened RTG's to take impacts would allow the possibility of long lifetimes but would probably cause the mass of the penetrometer to increase significantly.

c. Science Payload

The large independent penetrometer might carry an entry science payload consisting of stagnation pressure, accelerometer triad, mass spectrometer, altitude radar, and impact accelerometer and a landed payload consisting of a facsimile camera (2 days operation), a meteorology package, and a subsurface temperature probe. The small penetrometer would carry an accelerometer, aluminum oxide hygrometer (humidity detection), and soil moisture and soil temperature sensors.

d. Spacecraft Characteristics

The spacecraft characteristics of the penetrometer concepts discussed here are given in Figures A I-3 and A I-4.

e. Spacecraft Configuration

The penetrometer configurations discussed here are shown schematically in Figures A I-3 and A I-4.

A I.6. Viking

a. Objectives

The objectives of follow-on Viking missions are to continue the biological, geological, and atmospheric study of the planet, building on and reacting to the results of the Viking 75 mission.

b. Mission Description

Viking follow-on missions would be flown in 1979 or 1981 (a somewhat more difficult mission). They would consist of two spacecraft launches, each a combined orbiter/lander. The mission mode is as Viking 75 - inject into a 24.6 hour orbit, separate the lander after landing site certification by the orbiter cameras, entry, landing, and scientific observation and experimentation for a minimum period of 30 days. Independently, the orbiter conducts mapping, geoscience, and atmospheric studies.

c. Science Payload

The basic lander payload consists of biology, and geoscience packages which have been developed to react to Viking 75 results. For instance, the biology package could be an integrated biology instrument that builds on a positive biology finding by Viking 75 by beginning to characterize the Martian life. These science packages would replace current Viking 75 instrumentation as needed (depending on the 75 results). It is expected that the orbiter science payload would be little changed from the Viking 75 package with the possible exception of the addition or modification of one instrument.

d. Spacecraft Characteristics

The spacecraft characteristics are the same as Viking 75.

e. Spacecraft Configuration

The lander is shown in Figure A I-5.

A I.7. Viking Plus Rover

a. Objectives

The objectives of this mission are to continue the scientific exploration of Mars, building on and reacting to Viking 75 results. Biology, geoscience and atmospheric studies will be conducted by the lander/rover and geoscience and atmospheric studies by the orbiter. New and different landing sites will be explored.

b. Mission Description

The mission would be launched in 1979. Later opportunities cannot be accommodated without a major redesign of the orbiter propulsion system. The mission sequence from launch through landing is the same as Viking 75. After landing a small rover is deployed to enhance the sampling capability of the lander. The rover could be tethered to the lander by umbilical or free ranging. Studies are underway to define the maximum capability rover which Viking can deliver and to define the systems which best augment the Viking orbiter/lander science systems. Mission operations would continue for a minimum of 30 days. At the end of the nominal mission operations the rover, if free ranging, could be sent on an exploration mission limited in distance only by its communication and power capability.

c. Science Payload

The science payload is the same as that discussed for the Viking follow on mission with the exception that some science could be placed on the rover, depending on its size and complexity. Possible science capability as well as rover characteristics are shown in Table A I-2.

d. Spacecraft Characteristics

The lander and orbiter are essentially the same as Viking 75. Space is provided on the top of the lander for housing the rover and

Table A I-2

TYPICAL VIKING ROVER CHARACTERISTICS

	SMALL ROVER		MEDIUM ROVER	
	BASIC	ENHANCED	BASIC	ENHANCED
RANGE	50 m	100 m	1 km	10+ km
MASS	20 kg	30 kg	70 kg	~85 kg
SAMPLING	Scoop	Scoop	Scoop, Drill	Manipulator, Drill
SAMPLE ANALYSIS (On Rover)	Elemental	Elemental Mineralogical	Elemental Mineralogical H_2O	Elemental H_2O Meteorology
IMAGERY	None (Lander)	Monocular	Stereo, Quasi-microscope	Stereo, Quasi-microscope
DEPLOYED SCIENCE	None	Seismometer	Seismometer Seismic packets	Seismometer Seismic packets Mineralogical Analysis
POWER	Lander (Tether)	Battery (Lander recharge)	Battery (Lander recharge)	RTG/Battery
COMMUNICATION WITH EARTH	Via Lander	Via Lander	Via Lander	Via Lander or Orbiter
LOCAL CONTROL	Lander computer	Lander computer	Lander/Rover Computers	Lander/Rover Computers

its deployment ramp (Figure A I-6). Rover systems masses of up to 90 kg are under consideration and include tethered, battery powered, and RTG powered systems.

e. Spacecraft Configuration

The lander and orbiter configurations are the same as Viking 75. A candidate rover configuration is shown in Figure A I-7.

A I.8. Semi-Autonomous Roving Vehicle Mission

a. Objectives

The mission objectives are to conduct remote in-situ biological and geological investigations during an extensive automated traverse on the Martian surface in regions remote from acceptable landing sites.

b. Mission Description

The semi-autonomous rover would possibly be used as a tool in Martian exploration in the mid-1980 time period: 1983/84, 1986 or 1988. Upon embarking from the initial landing site, the rover would explore intensively several selected "major" science sites and conduct reconnaissance mapping during travel to each site. The design lifetime of the rover would be 1 year and over that period it would be expected to travel approximately 1000 km. The Shuttle/Centaur launch vehicle provides adequate capability during the designated launch period.

c. Science Payload

The science payload would consist of imaging sensors, biology, molecular analysis, meteorology and seismometry experiments; it could be very similar to the payload on the Viking lander. The payload possibly would be augmented with small, independent seismic or meteorological packages deployed by the rover at pre-determined locations. Payload weight range would be 50-70 kg.

d. Spacecraft Characteristics

The vehicle is characterized as a six-wheel, three-compartment articulated vehicle, weighing approximately 500-600 kg and powered by RTG's. In view of the roundtrip light time delay between Earth-Mars (8 min. minimum to 46 min. maximum), the limited communication visibility and sun elevation angles, the vehicle design is capable of performing many functions on-board, thus eliminating the need to communicate each operation through Earth. An on-board computer and sequencer performs the necessary computations, makes the decision and executes the events in their proper sequence. This spacecraft would not have a development predecessor.

e. Spacecraft Configuration

The rover configuration is shown in Fig. A I-8.

A I.9. Mars Surface Sample Return Mission

a. Objectives

The objectives of this mission would be to land on the Martian surface, gather a sample of the soil and possibly the atmosphere, control the environment of the sample during transit to earth and ensure safe recovery (avoiding back contamination) at earth.

b. Mission Description

The potential time frame would be in the late 1970's or early 1980's; the 1979 opportunity would be the earliest followed by the 1981 and 1983/84 opportunities. This mission can be flown in several different modes: (a) the lander and earth return system can be direct entry and direct return, or out-of-orbit entry and direct return and (b) the lander can be delivered by a Mars orbiter which subsequently performs a rendezvous with the ascent system carried down by the lander. Other options exist at earth where sample recovery is made: direct entry at earth or orbital entry and recovery by the Shuttle. A single launch of a Titan III E/Centaur can inject adequate payload for most options. Mission lifetime approaches 3 years.

c. Science Payload

The basic payload consists only of the sample acquisition, transporter/processor, loader and the sample cannister assembly. Weight is about 65 kg, based on a proposed sample of 200 gms.

d. Spacecraft Characteristics

Implementation of this mission requires the development of the following spacecraft: (a) lander delivery spacecraft, which could be a flyby or orbiter; that is, a Mariner derivative; (b) lander which is a Viking derivative; (c) dual-stage ascent system, a new development; (d) earth return vehicle, an Intelsat and Pioneer derivative and (e) an earth orbiting capsule or a direct entry capsule, both new developments. The design philosophy adopted for this mission is one of maximum utilization of existing systems and minimum capability required to return the sample. Total injected mass (outbound) for this mission is approximately 3200 kg.

e. Spacecraft Configuration

A sketch of the lander configuration with the enshrouded ascent and earth return vehicle is shown in Fig. A I-9.

A I.10. Satellite Missions

a. Objectives

The objectives of satellite lander missions are to perform studies of Phobos and Deimos; to characterize these bodies in terms of their origin and geological evolution.

b. Mission Description

A variety of missions can be flown to Phobos and Deimos - orbiter, lander, combined Viking Lander-Satellite Orbiter or Lander, and satellite sample return. All missions can be accomplished by Viking derivative systems. Orbiter missions consist of bringing a Viking orbiter into station-keeping position with the satellite to perform imaging and other experiments. Lander missions consist of rendezvous and docking with the satellite by a Viking orbiter equipped with landing legs and appropriate science instrument modifications. Sample return missions add an Earth return module to the lander for return of the sample to Earth by a direct entry and landing mode. This mission would use the same Earth entry vehicle and Earth return vehicle as the Mars sample return mission. Thus the satellite sample return mission could serve as a test of two of the critical elements of the Mars sample return (and help amortize the cost).

c. Science Payload

Orbiter - Visible and IR spectrometry, X-ray fluorescence, gamma-ray spectrometer, and TV camera.

Lander - X-ray diffraction, optical microscopy, alpha backscatter, X-ray fluorescence, gamma-ray spectrometer, and facsimile camera.

Combined Viking lander and satellite. Orbiter or lander - Same as Viking 79 for the Mars lander and the same as the orbiter or lander above depending on which mode is chosen.

Sample return - The science payload would be the same as the lander above in addition to the returned sample.

d. Spacecraft Characteristics

Power, communications, computer, etc. would be essentially the same as the Viking orbiter for the satellite orbiter and lander missions. The sample return mission uses the same basic system through satellite landing and sample acquisition, then uses planetary explorer technology for the return vehicle.

e. Spacecraft Configuration

A typical satellite lander is given in Figure A I-10 and the baseline sample return sequence is shown in Figure A I-11.

FIGURE A I-1: MOSS SPACECRAFT CONFIGURATION

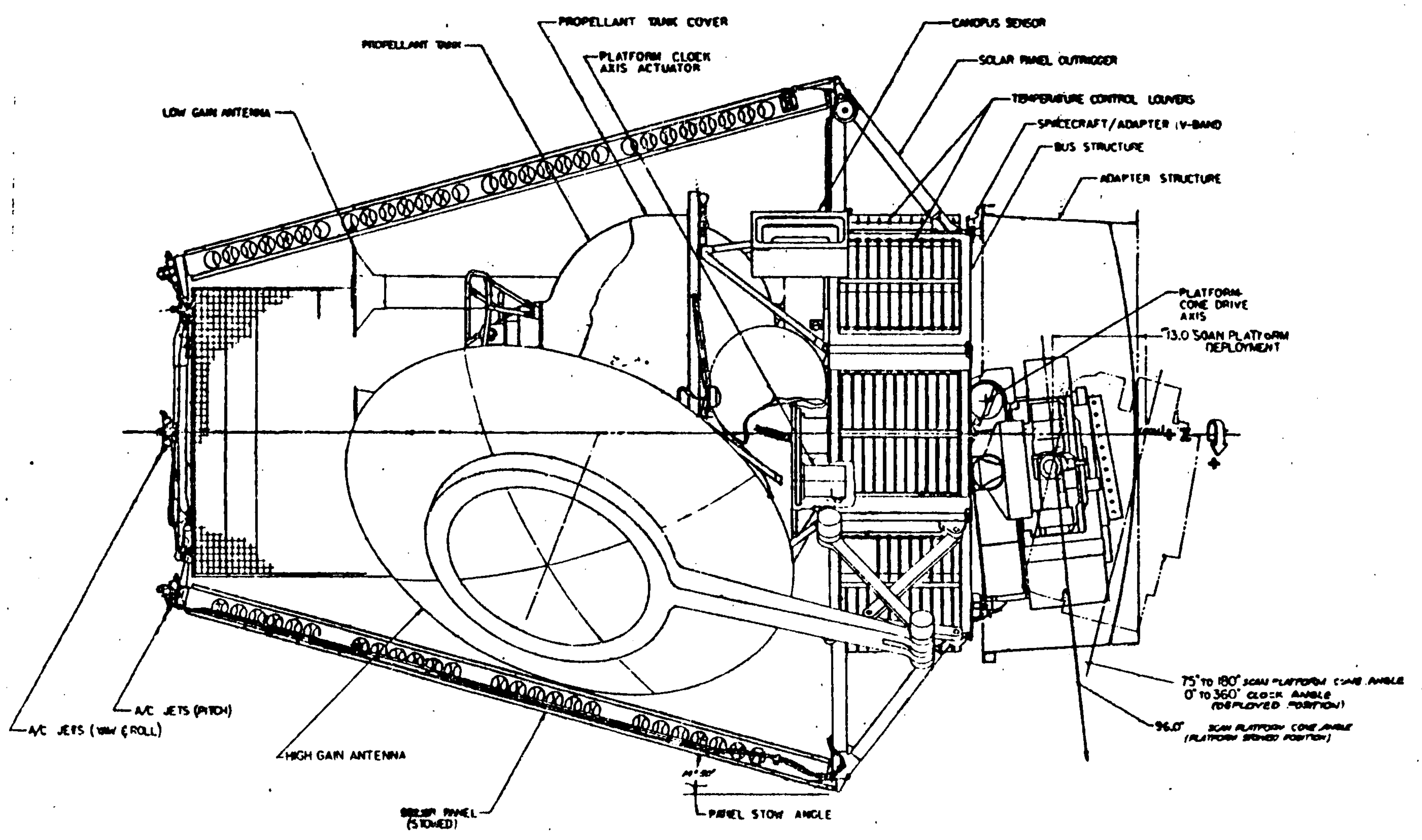
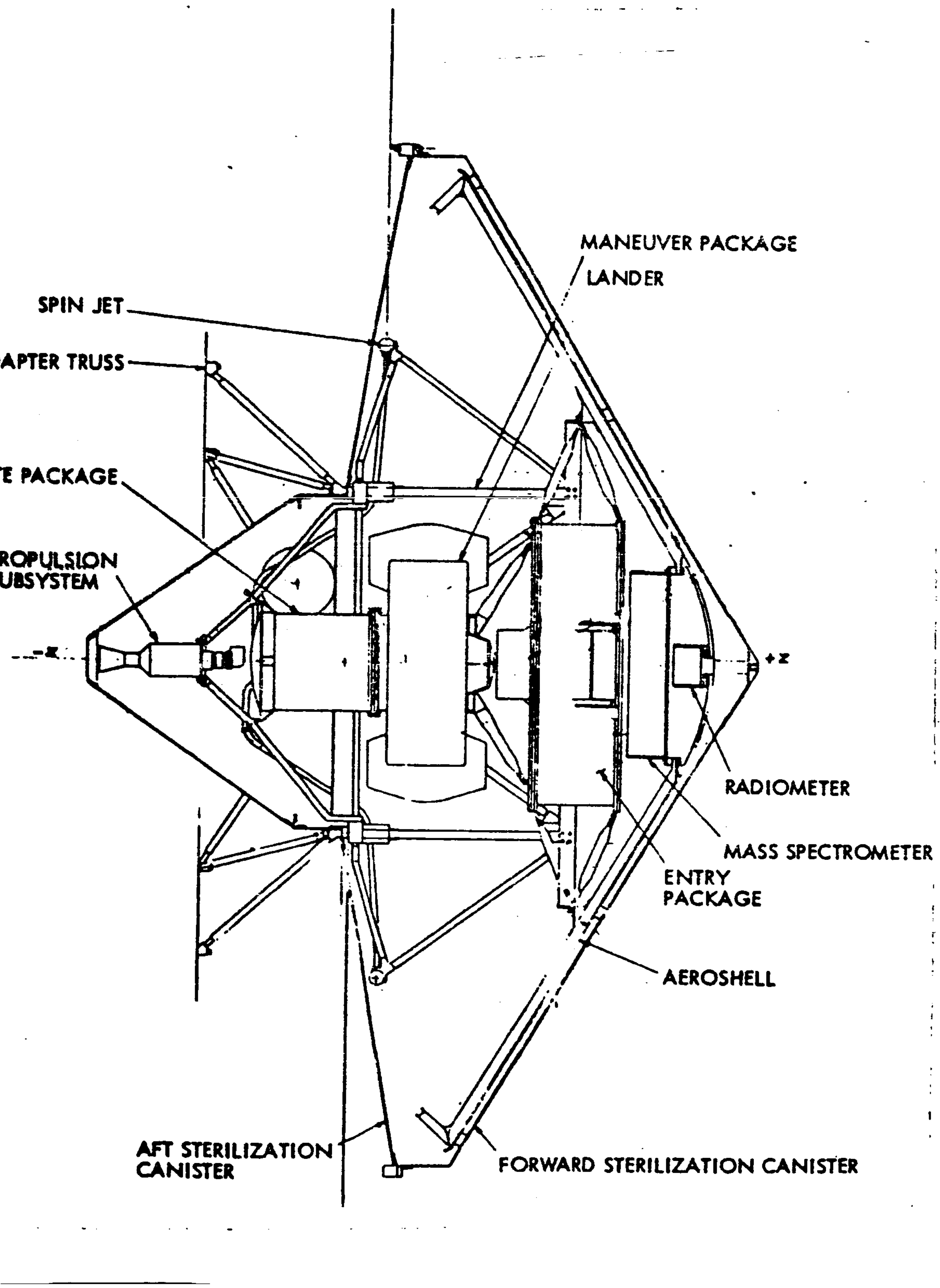


FIGURE A I-2

CSAD HARD-LANDER DESIGN CONFIGURATION



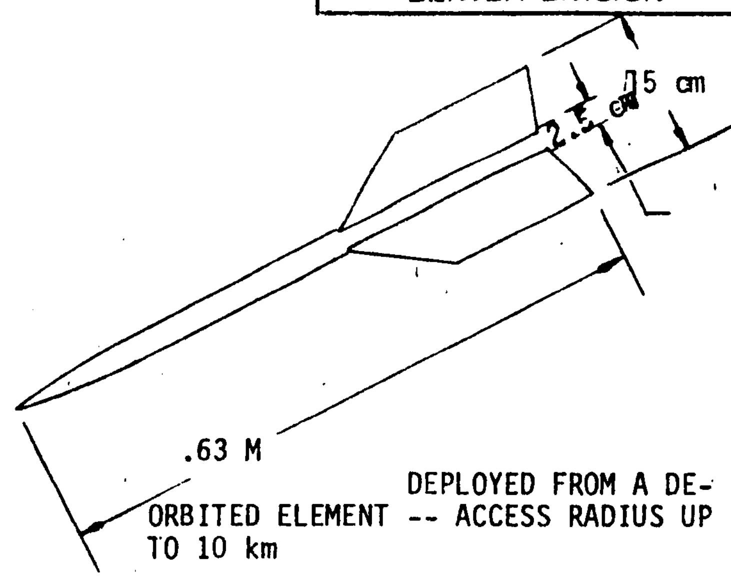
PENETROMETER - SUBORBITAL DROP

MARTIN MARIETTA
DENVER DIVISION

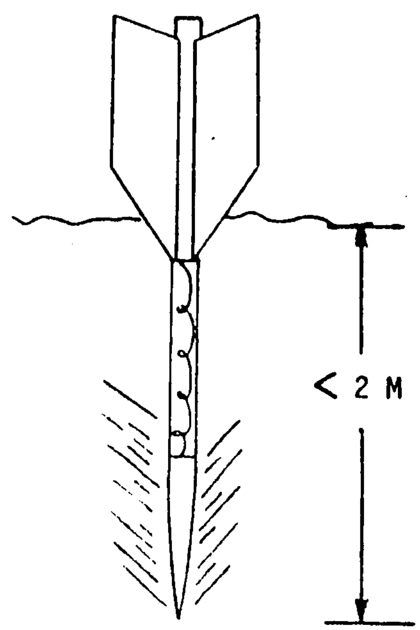
RELEASE ALTITUDE	2130m (< 7000 ft)
IMPACT VELOCITY	<153 m/sec (~ 500 ft/sec)
IMPACT DECELERATION	<800 g
PENETRATION DEPTH	1-2 m

SCIENCE PAYLOAD:
- Accelerometer
- Aluminum oxide hygrometer (humidity)
- Soil moisture
- Soil temperature sensors

SCIENCE WEIGHT	1 kg (2 lb)
VEHICLE WEIGHT	2.9 kg (6.5 lb)
TOTAL IMPACT WEIGHT	4.2 kg (9.1 lb)
DATA STORAGE	8 K bit
DATA RATE (RELAY)	28.2 K bps (impact) 14 bps (normal, 20 seconds every 8 hrs)
LIFETIME	to 90 days

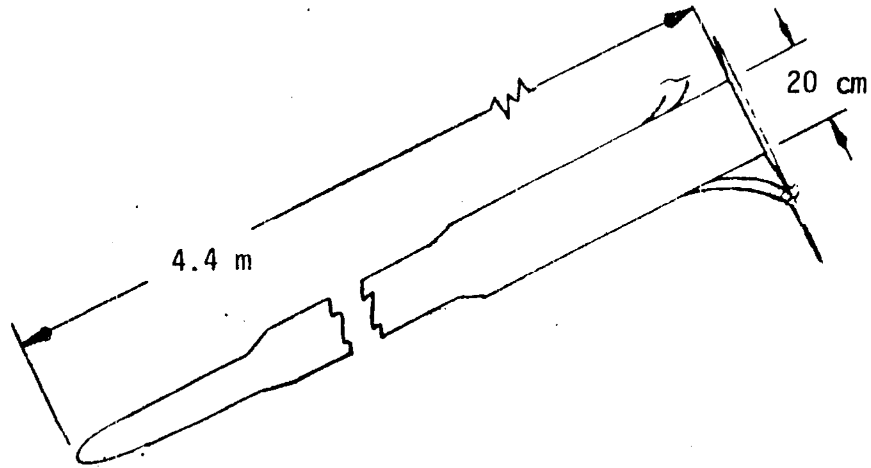


DEPLOYED FROM A DE-ORBITED ELEMENT -- ACCESS RADIUS UP TO 10 km



PENETROMETER CONCEPT - ORBITAL OR DIRECT ENTRY DROP

MARTIN MARIETTA
DENVER DIVISION



INSTRUMENTATION:
- Entry - Stagnation Pressure
  - Accelerometer Triad
  - Mass Spectrometer
  - Altitude Radar
  - Impact Accelerometer
- Landed - Facsimile Camera (2 days)
  - Meteorology (90 days)
    - Ambient pressure
    - Ambient temperature
    - Moisture
    - Wind speed
  - Subsurface Temperature

SCIENCE WEIGHT	9.6 kg (21 lb)
TOTAL WEIGHT	152 kg (335 lb) (incl 200 mps deorbit propulsion)
DATA STORAGE	10^5 bits
DATA RATE	3 KBPS (to Orbiter), 1 BPS (to Earth at periods)
LIFETIME	2 day facsimile 90 day meteorology
PENETRATION	$<$4 m (13 ft)
IMPACT VELOCITY	130 mps max (425 ft/sec)
DECELERATION SHOCK	1200 g max (short period)
POWER AVAILABLE	Battery - 1055 watt-hr

DEORBIT STRATEGY:

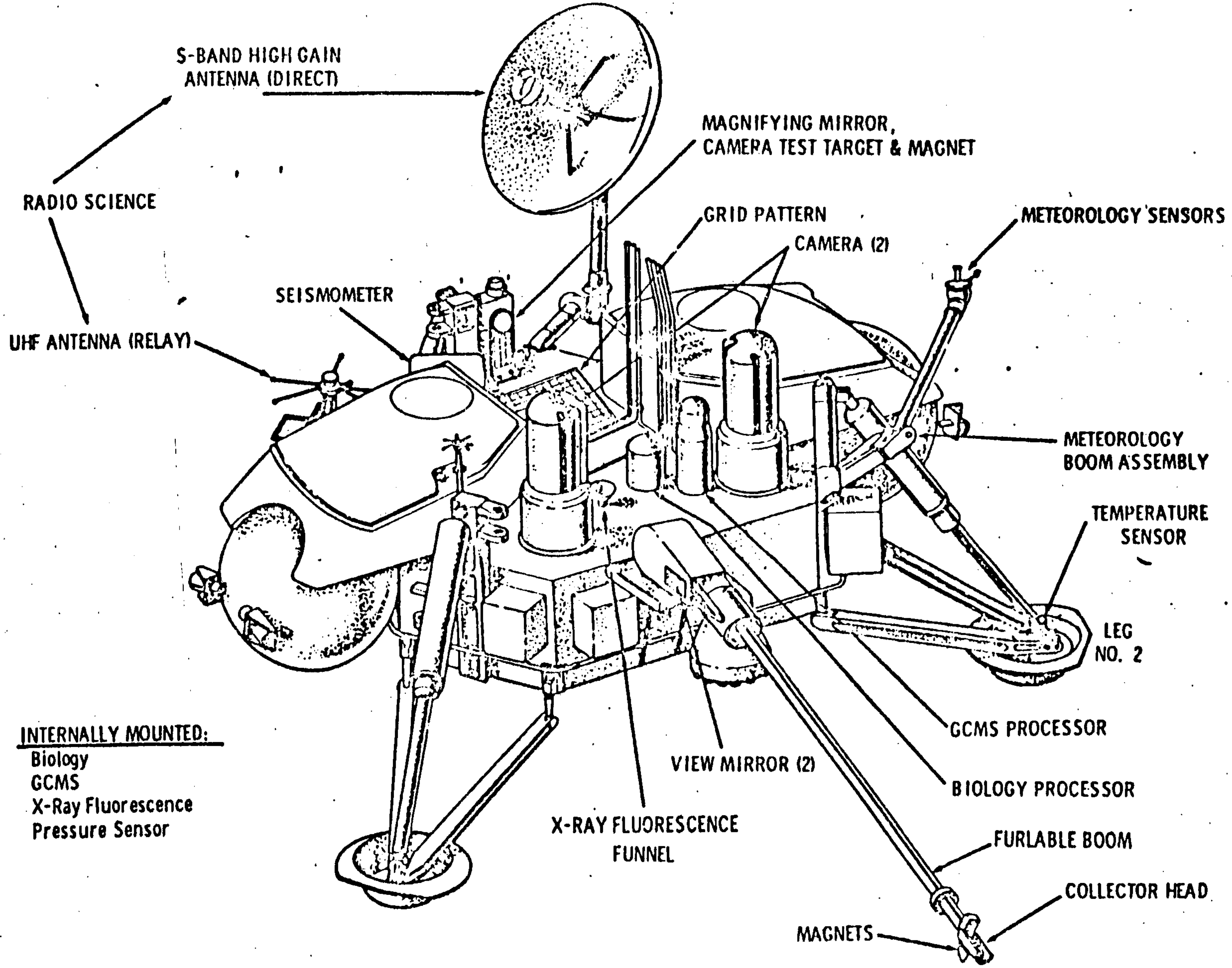
POINTED BY ORBITER
DEORBIT ΔV BY SOLID PROPELLANT MODULE
DRAG RING DECELERATION IN ATMOSPHERE

DIMENSION REFERENCE:

LENGTH:	4.52 m (178")
DIAMETER:	.20 m (7.87")
VOLUME:	.128 m^3 (4.5 ft^3)

VIKING '75 LANDED SCIENCE CONFIGURATION

D6A
6/72



INTERNALLY MOUNTED:
Biology
GCMS
X-Ray Fluorescence
Pressure Sensor

Figure A I-5

VIKING LANDER WITH SMALL ROVER

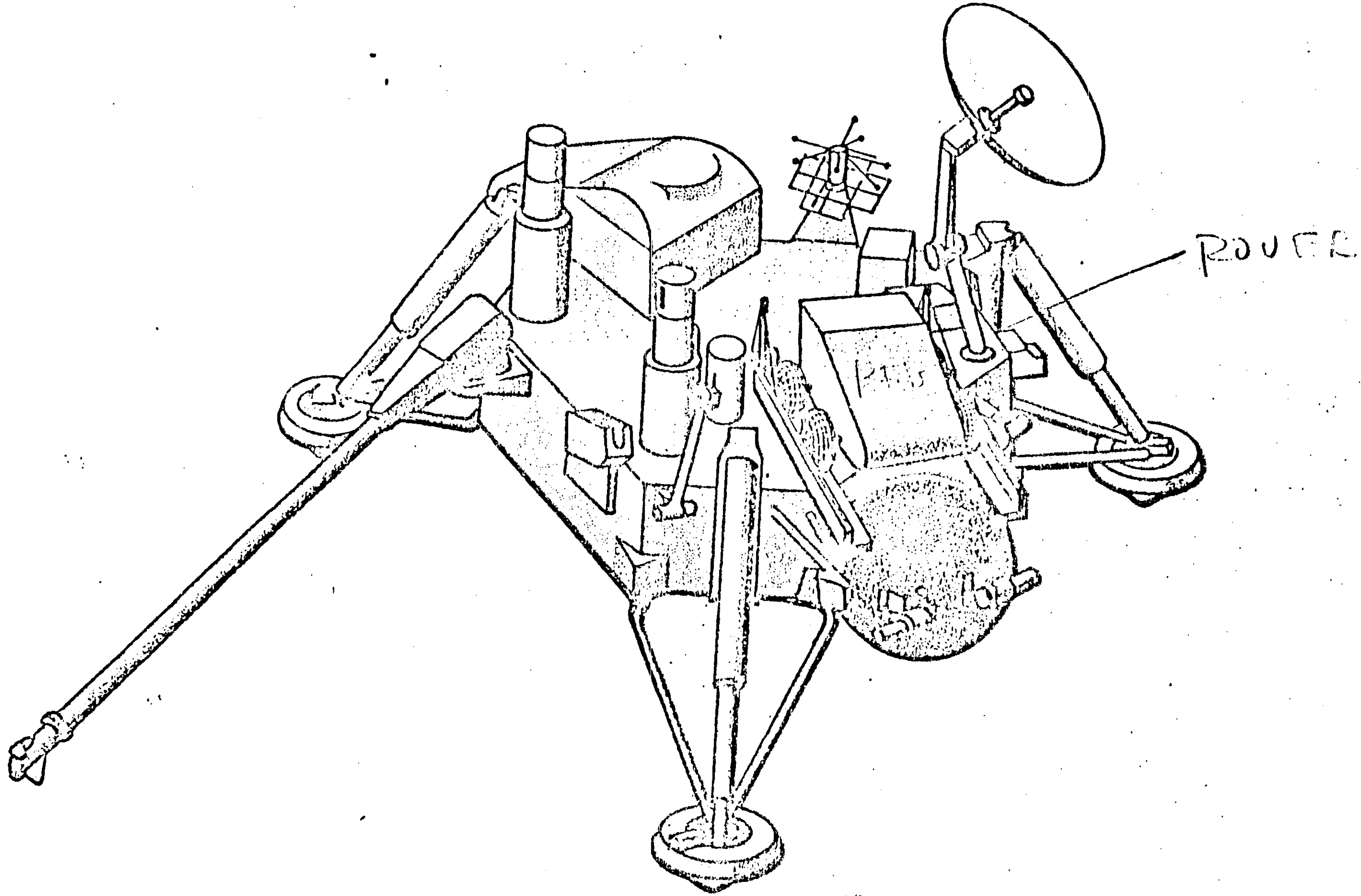


Figure A I-6

~~ROVER EXPLORING MARS~~
SMALL ROVER (20 - 90 kg class)

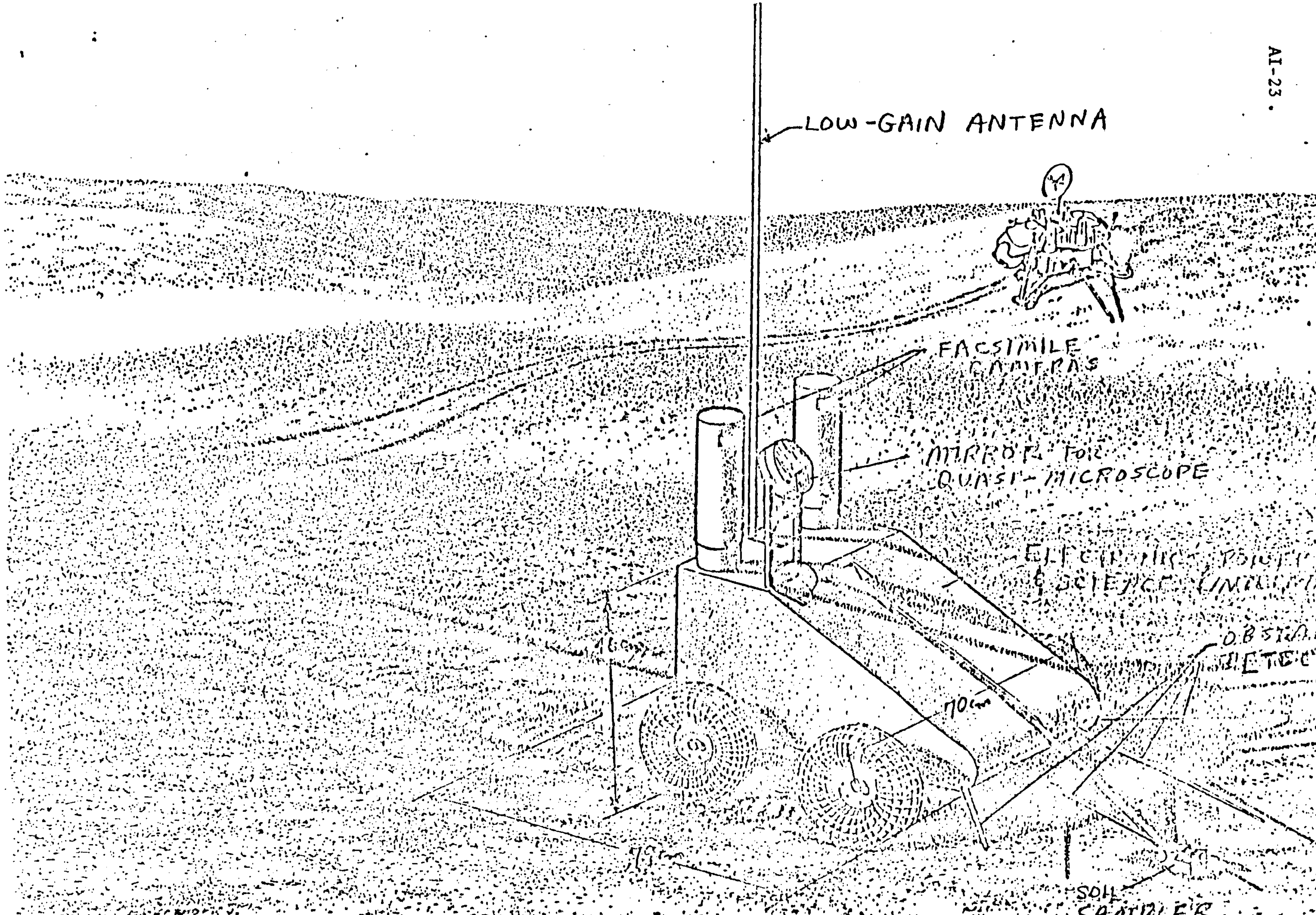


Figure A I-7

FIGURE A I-8

ROVER CONFIGURATION

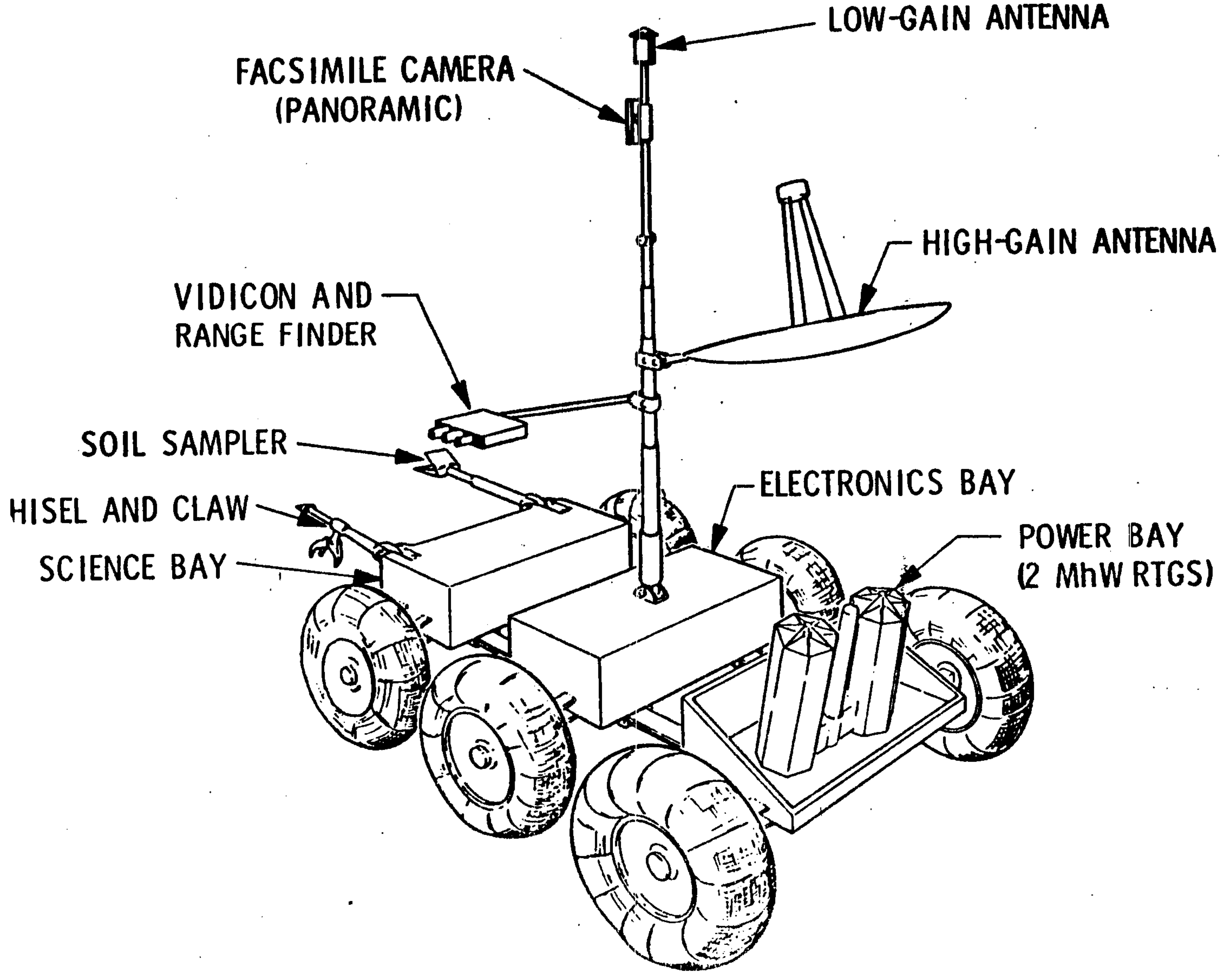
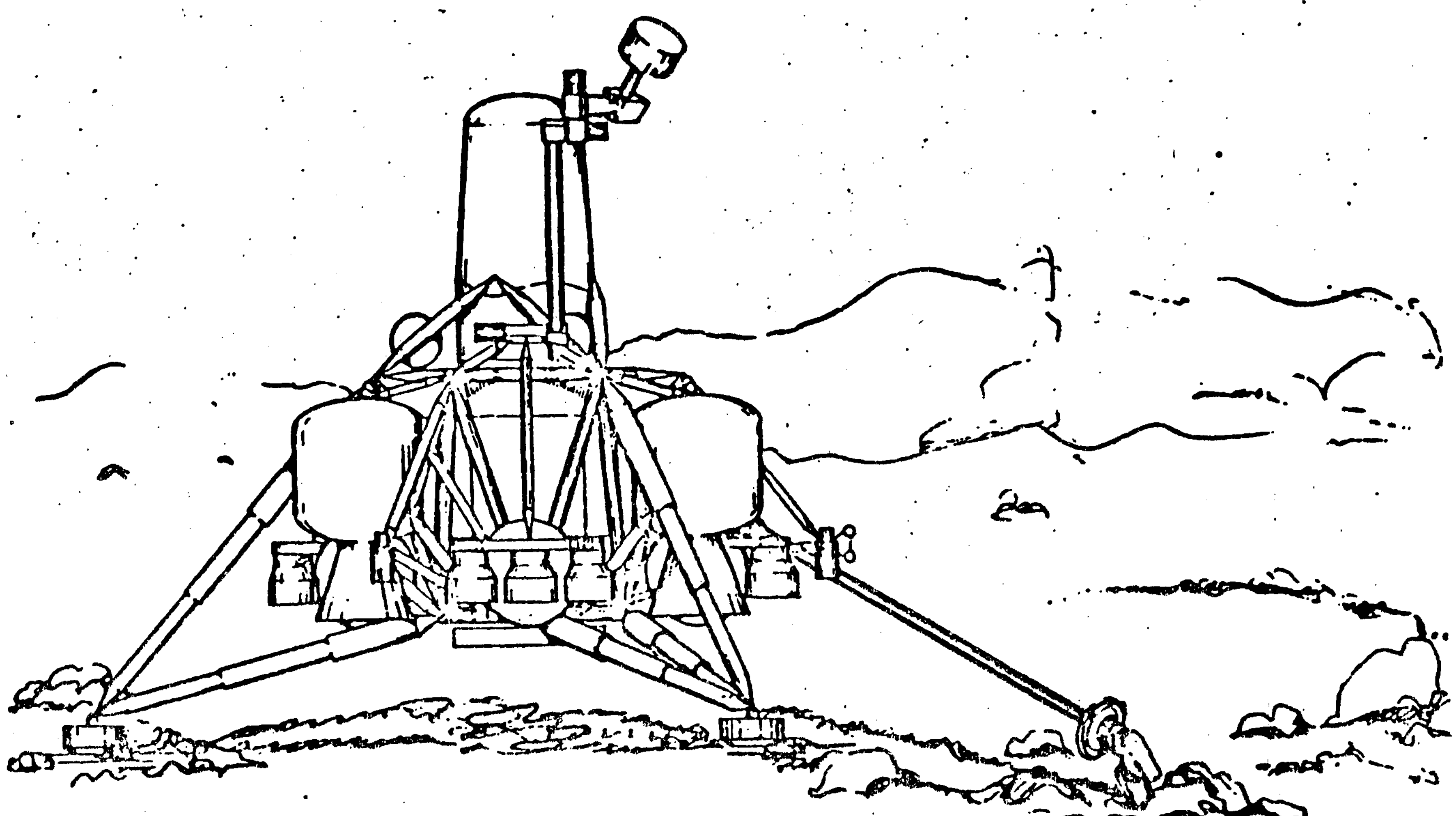


FIGURE A I-9: SAMPLE RETURN LANDER CONFIGURATION



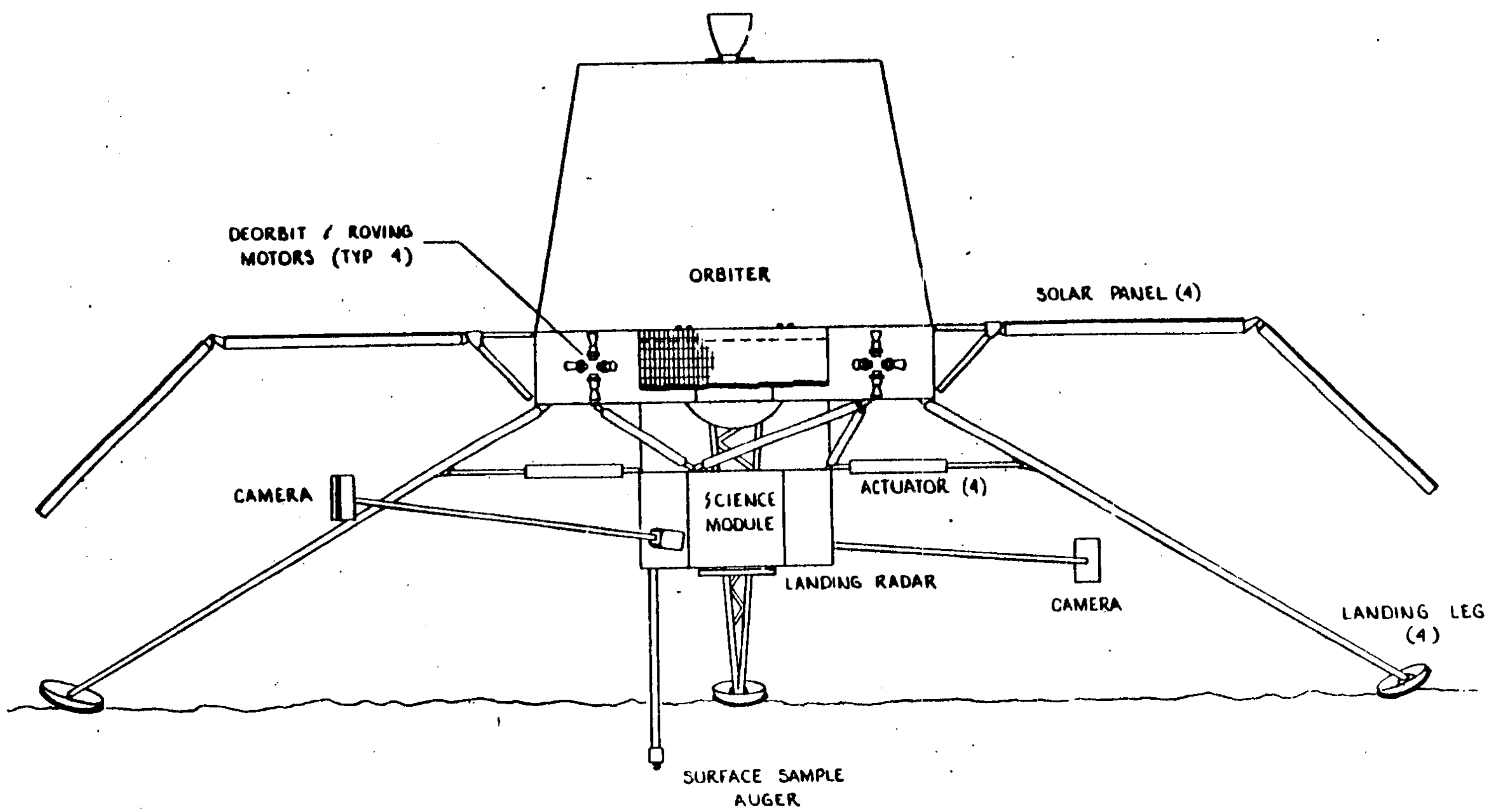


Figure AI-10Phobos/Deimos Landed Orbiter (Landed Configuration)

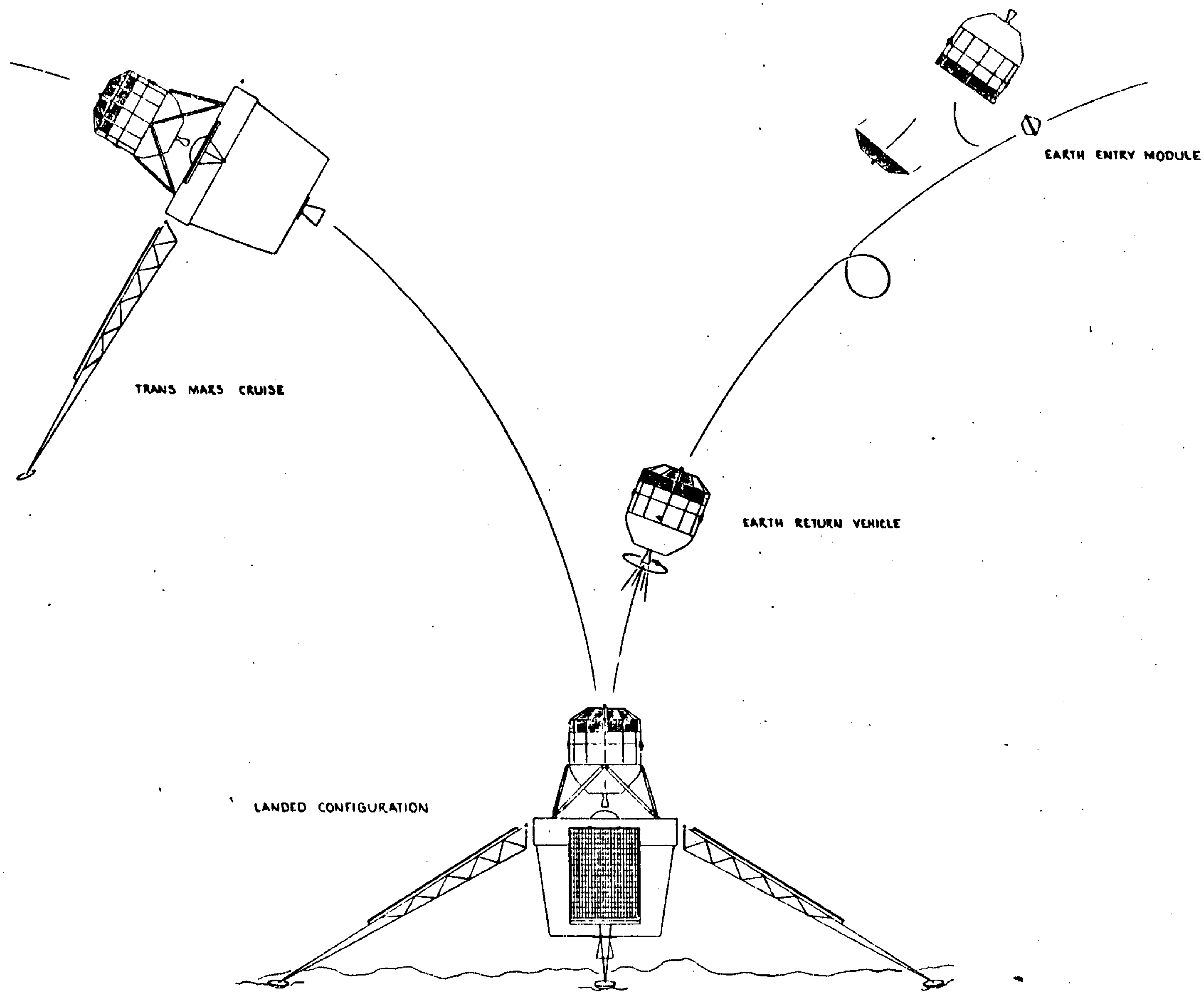


Figure AI-11 Baseline Sample Return Sequence

APPENDIX II

SR&T ADVANCED INSTRUMENT DEVELOPMENT

A II.1. Planetary Biology SR&T

a. Light Scattering

A light scattering experiment which measures increases in numbers of organisms in solution by optical methods, during incubation of soil and medium in a suitable chamber, has been developed. This experiment underwent extensive scientific testing and some instrument development prior to being dropped from the Viking 1975 biology instrument. This experiment is still a good candidate for life detection, as well as characterization, since it has the potential for amplifying (by stimulation of growth) biological signals which may be too low to detect or analyze.

b. Gas Chromatography

The gas exchange experiment on Viking 1975 utilizes a gas chromatograph for detection of changes in headspace gases during incubation of soil with a suitable medium. The GC portion of this instrument forms the basis for an advanced GC system, independent of mass spectrometry, which has been proposed for analysis of the atmosphere of Venus, and which could be modified for Martian application. A preliminary design for this instrument, which utilizes Viking 1975 components, has been completed; and the design parameters have been identified and verified with test data from instrument breadboards in the contractor's laboratory. The system analyzes unambiguously the following gases and vapors: H_2O, Ar, SO_2, Ne, N_2, HCl, CO, CH_4, NH_3, COS, H_2S, O_2, and H_2 at the 5-100 ppm range (except H_2) in the presence of 95% CO_2. The nominal system requires a two-column configuration and uses a thermal conductivity detector.

c. Advanced Label Release

An advanced label release experiment has the potential for providing a wealth of information on characteristics of a Martian biota by making some changes to the basic Viking 1975 label release procedure and hardware. The contractor has been using this concept to study a variety of biological responses from soil organisms including substrate specificity, elucidation of metabolic pathways, and the effects of moisture, temperature, composition of the gaseous atmosphere, pH and antimetabolites. Recent technique development has shown that some of these phenomena may be studied by multiple addition of media to a single soil sample in a single culture chamber. The major modification of the current Viking hardware design would involve substitution of a multiple substrate storage bank, selector, and sequential applicator for the presently existing single medium addition system. The incubation chamber and C^{14} detectors would not be changed. In addition to continued testing of various substrates and conditions, the contractor is developing a rationale for a substrate addition series and defining an experimental sequence. Also, the current Viking instrument will be examined for compatibility with multiple addition experiments; and software and minimum hardware changes required will be identified.

d. Wet Chemistry for Amino Acids

A system is being developed which will include the ability to chemically extract a soil sample, thus adding a high degree of specificity to the organic analysis and permitting the identification of specific molecules of biological interest. A contractor is currently developing a semiautomated prototype instrument for analysis of amino acids. The basic requirements for this instrument are that it be capable of determining which of 27 different amino acids are present, the concentration of each at a minimum of 0.1 nano mole/cc of soil, and the optical purity of the enantiomers. The analytical technique involves soil hydrolysis and purification, and isolation and derivitization of the amino acids. The resultant diastereoisomers are separated with a single, capillary-type, gas chromatographic column. Detection is by flame ionization and identification by characteristic retention times. Currently, the performance capabilities of the prototype instrument are being evaluated. The studies completed to date have demonstrated the feasibility of this instrument within the constraints of weight, power, volume and other Viking lander interface requirements and the means of avoiding ambiguities with unexpected amino acids. One possibility being investigated is the incorporation of a mass spectrometer (the Viking instrument) downstream of the gas chromatographic column for specific molecular identification.

e. Unified System for Biology and Chemistry

A unified instrument is being designed for the detection and characterization of life by progressing from very general inferential experiments to specific metabolic probes. These experiments are all based on the concept of putting soil into an enclosure and monitoring the mass spectrum of the gases above the soil, at periodic intervals, after making addition of selected nutrients to the soil. A contractor has defined a baseline system which is compatible with the weight, dimensions, power, and thermal limits of the Viking 1975 biology or GC-MS instruments. This system contains 11 experimental chambers or capsules mounted on a carousel. Following addition of soil, each capsule is sealed with a cap containing 2 breakable ampoules filled with the desired additive. A system of controlled leaks allows the mass spectrometer to sample the headspace gases in each capsule at selected times. A wide variety of experiments can be performed depending upon the contents of the ampoules. With no additions at all, a minimum disturbance experiment can be carried out, and the effect of incubation temperature measured; for instance, addition of water or organic substrates can stimulate growth and metabolism in the sample. The next step in the graded approach would be to add specific metabolites labeled with stable isotopes to identify metabolic pathways and energy mechanisms. Finally, in addition to biological reactions, this system allows direct chemical analysis of the soil sample by addition of specific reagents and observation of the gases evolved. In this way, nitrate, nitrite, ammonia, amino nitrogen, total carbon, carbonates and water can be measured. The technologies of ampoule sealing and closure have been tested. The technologies of nutrient injection, mass spectrometry, noble gas pumping, soil contamination protection, and gas sampling have been defined and are now undergoing construction and testing.

f. Sample Return

The concept of returning a sample of Martian soil to Earth for detailed study in the laboratory is being studied. The problems of back contamination and the requirements for bio-assay and quarantine procedures are also being studied. Clearly, if life exists on Mars, extraordinary care must be taken before samples are brought to the Earth. Even if Viking does not detect life on Mars, this cannot be taken as conclusive evidence of the absence of life, and returned samples must be quarantined in some fashion on Earth or in Earth orbit. These procedures are being studied and defined.

g. Other Concepts

A number of other concepts are being explored for possible Martian application. These include: microscopy, advanced pyrolytic techniques, *in situ* experimentation, detection of biopolymers, etc.

A II.2. Planetology SR&T

a. Alpha X-ray

The alpha particle experiment is designed to provide a detailed chemical analysis of Martian surface. A preprototype instrument utilizing the classical alpha and proton modes has been constructed and measurements demonstrating the analytical capabilities of this technique have been performed under simulated Martian conditions.

During the last year an X-ray mode has been added to the original alpha particle instrument. This mode involves the detection of X-rays produced by the alpha particles as well as by the X-rays and γ rays from the Cm^{242} sources. At present a very high resolution commercial X-ray detecting system with an intrinsic germanium detector (cooled with liquid nitrogen) is being used in the laboratory; however, it is planned to make measurements with a flight type X-ray detecting system with a Joule-Thomson cooling system. The dimensions of the head are $5 \times 5 \times 4$ cm not including provisions for the X-ray mode. The important components are a set of six Cm^{242} alpha sources, a mechanical shutter, and two detecting assemblies. Each detector assembly consists of three solid state detectors.

The alpha particle technique, as implemented until now, utilized only the scattered alpha particles and the protons from (α,p) reactions. These are particularly suitable for the determination of the light elements (for example, carbon through silicon) where the resolution is very good.

In order to supplement the desirable characteristics of the classical alpha particle technique for the light elements and to make a more ideal analytical tool for remote chemical analyses, it was decided to add another mode--the X-ray mode. Recent developments in semi-conductor solid state detector technology indicate that this is feasible for the next Mars missions.

b. Sub-Surface Water

The objective of this project is to develop instrumentation to determine the amounts and forms of water present in the surface and subsurface soil of planetary bodies. The concurrent development of scientific models of the water balance of the major planetary bodies is a necessary part of this objective.

During FY 73 a science breadboard soil water analyzer based on thermal separation of soil water with effluent gas analysis was designed and fabricated. The design incorporates differential thermal calorimetry to accomplish the separation and quantitative measurements of the water evolved and a thermal conductivity method of effluent gas analysis. The science breadboard is now undergoing performance tests to provide data needed in the design of an engineering breadboard. An engineering breadboard version of the existing soil water analyzer will be designed and fabricated in FY 74. This model will be subjected to tests using simulated Martian soils. The available water detectors that could function as interchangeable sensors in the effluent gas analysis will be evaluated.

c. X-Ray Diffractometer

A diffractometer designed for remote analysis has been breadboarded and tested at JPL. In the Seeman-Bohlin geometry the source image, the powdered sample, and the detector slit all lie on the circumference of the focusing circle. The conventional Seeman-Bohlin optics have been modified, however, by placing a line source directly on the focusing circle. This arrangement provides the most effective utilization of the source. This configuration also lends itself to combination with non-dispersive X-ray spectroscopy for elemental analysis, in which the source would either be the same X-ray tube used for diffraction or a radioisotope. The most suitable detector for this system would be a small silicon solid state detector.

During the past couple of years the IIT Research Institute has been developing a curved position-sensitive proportional counter which allows the location of a single stationary detector on the circumference of the focusing circle. Spatial resolutions of 0.4 - 0.5 mm have been achieved to date. The significant advantages of the position-sensitive counter are that it makes possible the simultaneous collection of the entire diffraction pattern with a consequent reduction in the time-power product parameter and eliminates the need for mechanical movement by the detector. Still to be resolved are the extent of degradation caused by slant path effects at low angle in the absence of a receiving slit and the means of achieving the necessary strength and rigidity for the long anode wire.

d. Advanced Seismometer

The ultimate objective of this instrument is to conduct an experiment to map the internal structure of the planet Mars: to determine the distribution of "Marsquakes," and the composition and size of the core.

The Viking '75 seismic experiment has a resolution to ground motion of 1 millimicron at 0.25 sec period and is adequate for a first sampling of the Martian seismic environment. An advanced seismic instrument will require instruments with greater dynamic range and resolution and a much wider bandwidth in order that short period body waves (1 sec) and free modes of oscillation of the planet (30 min) may be studied. Investigations have been performed to more clearly define and evaluate instruments and approaches applicable to this advanced research. Instruments with a short period sensitivity an order of magnitude greater than Viking '75 (i.e., 1 angstrom) and two orders of magnitude greater sensitivity at periods greater than 100 sec are conceived.

In this phase, work will be directed toward the design and construction of the sensor suspensions, position-zeroing methods and packaging necessary for the highly stable seismometers demanded by the desired long period sensitivity, and to the transducers and electronics required.

e. Advanced X-Ray

Work will be directed toward improving the identification of elements in the lower mass range, decreasing weight and power requirements, and utilization in an in situ mode.

f. Imaging Systems

Future exploration with imaging instruments will be aimed not only at the inner planets, but will also include the outer planets of the solar system and their satellites. To explore the outer planets, the imaging instruments will be required to have lifetimes ranging from 4 to 10 years. The instruments must measure natural phenomena over a broader spectral range with greater sensitivity and better photometric stability than is achievable with current instruments. The proposed effort is intended to provide, for use on future planetary spacecraft, imaging instruments capable of meeting these broad requirements.

A silicon vidicon camera will be developed to the point of demonstrating the feasibility of adapting silicon vidicons to Mariner type imaging instruments. Included will be a design capable of cooling the vidicon target to -40°C. The mechanical design must be capable of supporting the vidicon in not only the anticipated thermal operating environment, but also the launch environment. Upon completion of the demonstration of thermal and mechanical design feasibility, this task will refocus on development of solid state sensor imaging instruments.

Solid state sensors are becoming available which provide in addition to the advantages associated with silicon vidicons (increased sensitivity, broader spectral response, longer life) possible further increases in sensitivity coupled with reduced complexity and lower weight. These advantages will translate into lower cost for imaging experiments. Over a several year period, linear and area array cameras will be developed utilizing the most recent technology available in imaging solid state sensors. The instruments will be simpler and have less impact on the spacecraft than current designs since fewer interfaces will be required, and the increased sensitivity can be used to relax spacecraft stability requirements.